Hydropower Investment and Public-Private Ecosystem Assessment

Greg Stark, Tessa Greco, Aaron Levine, Michael Ingram, and Stuart Cohen

National Renewable Energy Laboratory

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List of Acronyms

ACORE	American Council on Renewable Energy
CAISO	California Independent System Operator
CCA	community choice aggregator
CPUC	California Public Utilities Commission
CWIFP	Corps Water Infrastructure Financing Program
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	U.S. Energy Information Administration
ELCC	effective load-carrying capability
EPAct	Energy Policy Act
EPC	engineering, procurement, and construction
ERCOT	Electric Reliability Council of Texas
ESG	environmental, social, and governance
FDIC	Federal Deposit Insurance Corporation
FERC	Federal Energy Regulatory Commission
GDO	Grid Deployment Office
GW	gigawatt
IIJA	Infrastructure Investment and Jobs Act
INL	Idaho National Laboratory
IPP	independent power producer
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
ISO	independent system operator
ISO-NE	Independent System Operator-New England
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of energy
LMP	locational marginal pricing
LPO	Loan Programs Office
MISO	Midcontinent Independent System Operator
MOU	memorandum of understanding
MW	megawatt
MWh	megawatt-hour
MYPP	Multi-Year Program Plan
NHA	National Hydropower Association
NPD	non-powered dam
NPR	Notice of Proposed Rulemaking
NREL	National Renewable Energy Laboratory
NYISO	New York Independent System Operator
OCED	Office of Clean Energy Demonstrations
ORNL	Oak Ridge National Laboratory
PE	private equity
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PPA	power purchase agreement

PSH	pumped storage hydropower
PTC	production tax credit
PURPA	Public Utility Regulatory Policies Act
RCEA	Redwood Coast Energy Authority
REC	renewable energy certificate, also known as renewable energy credits
RPS	renewable portfolio standard
RTO	regional transmission organization
SCEP	State and Community Energy Programs
SPP	Southwest Power Pool
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
VC	venture capital
VRE	variable renewable energy
WPTO	Water Power Technologies Office

Executive Summary

Hydropower plays a key role in the United States energy generation mix, representing nearly a third of U.S. renewable energy generation today (Uría-Martínez and Johnson 2023). Pumped storage hydropower (PSH)[1] currently represents 96% of utility-scale energy storage capacity and 70% of grid storage capacity and supports grid stability and reliability across the country (Uría-Martínez and Johnson 2023). Despite the potential of these technologies to support the U.S. clean energy transition, new public and private investment in hydropower projects of all sizes lags other renewable energy generation sources such as wind and solar (Munsell 2014; Levitan 2014). Between 2005 and 2022, the United States substantially increased its solar and wind generation capacity, adding 71.7 gigawatts (GW) and 132.2 GW, respectively (U.S. Energy Information Administration [EIA] 2023b). In contrast, hydropower and PSH capacity increased by 2.5 GW and 1.7 GW, respectively, between 2005 and 2022 (EIA 2023b).

The 2016 U.S. Department of Energy (DOE) *Hydropower Vision* report (DOE 2016) estimated that U.S. combined hydropower and PSH generating and storage capacity could increase by 49 GW from 2016 to 2050, significantly adding to the approximately 100 GW of existing capacity. To move closer to achieving this vision, the DOE Water Power Technologies Office commissioned this report to both understand the current hydropower investment landscape and review the primary challenges in raising investment within the United States for medium-sized hydropower and PSH; "medium-sized" is defined here as projects with 5 to 30 megawatts (MW) of installed capacity. Based on 33 stakeholder interviews, a survey of 36 industry representatives (including investors), and an analysis of recent public transactions, this report considers the investment and development trends and future opportunities for medium-sized hydropower in the U.S. market.

Developing new medium-sized hydropower and PSH could help advance the nation's clean energy transition. While the medium-sized hydropower market represents 6% of total hydropower capacity today, it is an important segment for future development (Johnson, Kao, and Uría-Martínez 2023). This is because most large-scale hydropower resources have already been developed, but the medium-size range offers potential for hydropower development with lower environmental impact[2] using existing infrastructure, modular components, and untapped resources. Recent technology advancements further support cost-effective development of these resources. Below, we discuss the current hydropower development pipeline, recent hydropower-related investment transactions, development risks, and mitigation measures that DOE and other government agencies could take to stimulate investment in this sector.

The current pipeline of medium-sized hydropower and PSH projects as of 2022 represents more than 1 GW of capacity (Johnson, Kao, and Uría-Martínez 2023). Using historic installed capital

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[1] PSH is a type of long-duration power storage using hydroelectric energy with two water reservoirs at different elevations. The system generates power during high-priced periods as water flows down from the upper reservoir to the lower reservoir, spinning a generation turbine. When power prices are low, grid electricity is used to pump the water back up to the upper reservoir for redeployment.

[2] Some medium-sized projects qualify as low impact per Federal Energy Regulatory Commission (FERC) regulations (FERC 2023e) and Low Impact Hydropower Institute criteria: https://www.hydro.org/powerhouse/article/certifying-hydropower-as-low-impact/.

costs as a guide,[3] the required investment to develop the current pipeline of medium-sized hydropower and PSH could range from $3.16 billion to $9.5 billion (estimated using installed cost estimates from Uría-Martínez and Johnson [2023][4]). Five project[5] types are represented: capacity additions, conduits, PSH (both open- and closed-loop), non-powered dams (NPDs), and new stream-reach development. Notably, NPDs represent 62% of projects in the pipeline (Johnson, Kao, and Uría-Martínez 2023). NPD projects may be more popular, as site surveys, environmental studies, and construction costs can be lower for NPDs compared to projects that do not start with existing infrastructure, though installed costs can still be high compared to other renewables—and licensing and permitting through multiple regulators can still be complicated. Investors surveyed and interviewed for this report were most interested in capacity additions, which represent the second largest category in the development pipeline—these upgrades typically require less capital expenditure than developing new facilities and may be included in the relicensing process. Capacity additions, NPDs of less than 10 MW, conduits, and closed-loop PSH also provide a unique opportunity for development given the exemptions and expedited licensing and permitting processes available from the Federal Energy Regulatory Commission (FERC), increased ability for modularity, and the generally lower-environmental-impact nature of development. Project developers surveyed for this report rated these facilities as likely for future development. Additionally, hybrid projects that pair hydropower or PSH with wind energy, solar energy, and/or battery storage also offer investment and project development opportunities for cost-efficient development.

A review of 43 medium-sized hydropower and PSH transactions over the past 10 years helps illustrate the current investment landscape. Independent power producers have been active in acquiring existing facilities or portfolios to add to their current fleet of hydropower and PSH assets, which carry lower operating and investment risks. Institutional investors, private equity funds, and venture capital funds are actively investing equity into innovative companies. Utilities have been active in acquiring facilities and financing various projects. Many utilities have access to early-stage funding and financing, particularly with corporate financing and municipal or revenue bond financing. Going forward, the pool of relevant investors in the market has the potential to expand to include community choice aggregators, commercial banks, tax equity investors, and others. Larger projects and portfolios of operating projects can typically seek financing with institutional investors, banks, and private equity funds.

In general, investors seek projects that minimize investment risks, achieve or exceed target rates of return, and match their investment horizon. To finance hydropower projects, these goals translate to a need for reduced project lead times, payback periods, and capital costs (e.g., through grants or low-cost government financing). Raising equity or debt is difficult for developers until they have obtained a license to operate due to the typically long and uncertain development timelines. The risks in development that were identified by the stakeholders who

[3] Based on capital costs from 80% of hydropower projects developed since 1980, which range from $3,000 to $9,000 per kilowatt (Uría-Martínez and Johnson 2023).
[4] While this estimate represents a wide range of costs due to large variation in capital costs based on project type and other conditions, the estimate provides a magnitude of investment required. However, this estimate is not indicative of actual investment needed, as some projects may already have the necessary funding.
[5] Project is defined here as potential new investment or development or expansion.

participated in this work can be summarized into six main challenge areas[6] with attracting debt or equity financing, described below.

- **Long project development timelines** associated with protracted federal, state, and local regulatory processes create challenges for project developers and investors. While low-impact hydropower projects of less than 10 MW (e.g., conduits) and closed-loop PSH have been afforded reduced permitting processes, hurdles in using exemptions and for nonexempt projects remain.
- **Lack of access to early-stage funding** makes it difficult for developers to overcome challenges in the development life cycle. With early-stage project risks and long lead times to operational cash flows, investors are likely to invest in the later stages of development once the permitting and licensing processes are underway or complete.
- **Challenges in securing early-stage power purchase agreements** can dissuade investors by increasing their exposure to revenue risk. These agreements, which identify a project's offtaker for energy, capacity, ancillary services, and/or renewable energy certificates, include an agreed-upon price schedule. As such, investors can estimate stable returns from future cash flows and mitigate risk associated with potential fluctuating market prices.
- **Market compensation uncertainties and lack of market parity** contribute to limiting a project's bankability and ability to raise financing. Compensation for grid services such as for capacity or ancillary services vary by market and are in marked flux.[7] Complicating the situation is that state renewable portfolio standards often have more stringent eligibility requirements for hydropower and PSH resources compared to other renewable resources, requiring the former to be more reliant on market compensation.[8]
- **High development costs** combined with long lead times to operational cash flows limit early investment interest for hydropower. Hydropower development requires significant up-front funding, and it can be years before revenue is realized. Together with market uncertainty, this can discourage investors who are seeking favorable near-term return on investment.
- **Limited industry awareness** restricts hydropower's market growth. Interviews with investors, specifically banks, revealed that many are not approached by developers for

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[6] In addition to the six factors identified above, unpredictable market factors like geopolitical events, technology advancements, and consumer behaviors can affect hydropower projects. Although the analysis has attempted to address these market risks, their complexity and volatility may need more attention. Policy risks also emerge as a key factor. Government policies can change and influence the project's feasibility and returns. A thorough exploration of policy and market risks was not possible in this study. These areas demand more detailed exploration, and future projects should aim to better understand and address these uncertainties.

[7] As fossil-fuel-fired generation is retired, revenue from capacity is expected to provide an increasing portion of hydropower's total revenue. However, capacity prices are currently extremely volatile, having fluctuated 93% in a recent Midcontinent Independent System Operator auction (https://www.utilitydive.com/news/miso-capacity-planning-resource-auction/650727/). It is unclear when prices are expected to stabilize.

[8] Renewable portfolio standards have specific eligibility requirements that prevent some medium-sized plants from qualifying, restricting their participation in the renewable energy certificate markets.

hydropower or PSH projects. Therefore, raising awareness of the benefits of hydropower and PSH for investors is an important step.

In addition to the initiatives DOE is already leading that support hydropower and PSH development, stakeholders shared that continued support could help spur future investment. Stakeholder recommendations for consideration by DOE and other government agencies include the following:

- **Provide financing, bridge funding, and support for early-stage development** through grants and technical assistance focused on activities such as (1) conducting pre-feasibility and feasibility studies or completing engineering and design studies, among others; (2) facilitating financing opportunities by helping project developers prepare their projects to meet investor standards; (3) emphasizing to the U.S. Army Corps of Engineers (USACE) the strong market interest to survey, rank, and bundle existing NPD assets (under USACE ownership) to then sell as bundles to the market; and (4) providing early loans and/or loan guarantees to help mitigate risk to investors.
- **Support market parity for hydropower and PSH** by (1) researching how to achieve market parity for low-impact hydropower, which could allow these projects to qualify to generate renewable energy credits like solar and wind projects, and (2) working with industry to increase supply of hybrid projects that have greater value in providing grid services.
- **Encourage updated market models and valuation methodologies** to help hydropower diversify and expand potential revenue sources, support revenue stability, and reduce the risk profile by (1) working with independent system operators, regional transmission organizations, and regulators regarding the challenges of investment decision-making under market uncertainty, and (2) developing new market models that better represent and value the services needed to meet energy and reliability challenges under evolving grid conditions. Such advancements would likely benefit all stakeholders and should allow developers and investors to better value, plan for, and estimate future investments.
- **Support the development of improved federal permitting and licensing processes** by working with federal regulatory agencies, including FERC, USACE, and the Bureau of Reclamation, to (1) identify opportunities for alignment of different agencies' permitting and licensing processes, building off existing agreements; (2) review previous relicensing cases to identify opportunities to improve future relicensing and reduce the risks of license surrenders; (3) clarify the expedited licensing processes for project developers; and (4) differentiate certain aspects of licensing requirements based on project size (or type). A reduced timeline for development could help reduce risks and add certainty to the project.
- **Continue to support new innovative research on reducing deployment time and costs**. Innovative demonstration projects and research should focus on decreasing deployment time and costs. Hydropower construction costs and capacity-weighted levelized costs are high compared to solar and wind. Identifying opportunities to decrease the up-front costs and help make hydropower more modular could reduce barriers to entry (i.e., using new and efficient technologies that offer low-impact and modularity) for developers and add certainty for investors.

- **Clarify new legislation and regulations and conduct outreach with developers and industry to request feedback and reduce unintended consequences**. As the new laws have substantive impact, developers are seeking further industry outreach and guidance around the changes to the tax credit eligibility for renewable generation sources mandated by the Inflation Reduction Act (January 2023). Key clarifications requested were related to domestic content requirements for qualification for program benefits, which has the potential to either increase hydropower and PSH project costs or impact program eligibility (See Section 6.2.6).
- **Increase awareness of new opportunities in hydropower.** Outreach efforts to communicate medium-sized hydropower and PSH's benefits and potential risk mitigations across the industry (targeting developers, investors, independent system operators, regional transmission organizations, and utilities) could help increase awareness and facilitate future consideration for their portfolios moving forward.

DOE and other government agency support for the activities above could help address the challenges inhibiting medium-sized hydropower and PSH investment. It is a unique time for the industry, given the hydropower incentives included in the Infrastructure Investment and Jobs Act and the Inflation Reduction Act. This report is an initial step for DOE in identifying opportunities to support investment in medium-sized hydropower and PSH deployment.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Purpose and Scope

The U.S. Department of Energy (DOE) Water Power Technologies Office's (WPTO's) hydropower program has a mission to "conduct research, development, demonstration, and commercial activities to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and PSH [pumped storage hydropower] technologies; better understand and capitalize upon opportunities for these technologies to support the nation's rapidly evolving grid; and improve energy-water infrastructure and security," as set forth in their Multi-Year Program Plan (MYPP) (DOE 2022). In 2016, DOE published the *Hydropower Vision* report, which found that hydropower could grow from 101 gigawatts (GW) of capacity in 2015 to nearly 150 GW by 2050 (DOE 2016). To achieve the desired outcomes established in *Hydropower Vision* and the MYPP, WPTO is identifying opportunities to encourage investment in hydropower as a crucial component to further scale this technology.

To support WPTO's mission of advancing hydropower and PSH technologies, this report provides an analysis of the current medium-sized pipeline, investment risks, compensation mechanisms, investment landscape, and strategies for hydropower and PSH project development in the United States. For the purposes of the research, medium-sized hydropower is defined as 5 megawatts (MW) to 30 MW[9] and includes both hydropower and PSH, unless otherwise specified. This report, which summarizes the research and analysis, achieves the following:

- Identifies market needs and deployment risks and challenges
- Presents an overview of the investment challenges and opportunities across the project timeline
- Identifies the investors in medium-sized hydropower development and their motivations
- Identifies strategic focus areas within the hydropower ecosystem to deploy funds, design or adapt programs, and establish collaborations with public and private entities
- Proposes potential areas of support for DOE to encourage additional interest and investment in medium-sized hydropower and PSH based on conversations within DOE and with industry.

1.2 Methodology

The development of this report involved both market research and stakeholder engagement. Thirty-three interviews were conducted with hydropower market stakeholders, including project developers and independent power producers (IPPs), institutional investors, private equity (PE) and venture capital (VC) funds, utilities, manufacturers, and commercial banks to gather perspectives on the current hydropower market landscape, investment challenges and

[9] The Federal Energy Regulatory Commission (FERC) uses different definitions of small-sized hydropower for regulatory purposes. FERC considers non-federally owned conduits with up to 40 MW installed capacity to be small for the purposes of licensing exemptions. FERC considers nonfederal, pre-2005 dams with up to 10 MW installed capacity to be small for the purposes of licensing exemptions (FERC 2023e).

opportunities, and potential opportunities for DOE to support medium-sized hydropower and PSH development.

To quantify current and future potential investor sentiment on hydropower, an anonymous investment survey was sent to 148 investors and developers. The investor group included current and potential future investors in hydropower and PSH, including IPPs, as well as utilities that internally and externally finance such projects. Potential investors were defined as those who have broad renewable energy portfolios. Developers referred more specifically to developers of hydropower or PSH projects. The survey targeted organizations that currently develop or invest in hydropower or may be interested in doing so in the future (i.e., those that have invested in other renewables) and requested that only one representative per company respond on behalf of their organization to minimize duplicative responses. During the 3 weeks the survey was active, representatives from 36 organizations responded (56% identified as investors and 44% identified as developers). Responses from the survey highlight market perspectives that reveal trends in industry activity and perceptions. However, the small sample size does not guarantee these views are statistically significant.

To understand the investment landscape, including the characteristics of active investors and motivations behind recent hydropower and PSH investments (described in more detail in Section 5), transaction data from the Oak Ridge National Laboratory (ORNL) HydroSource database, Infralogic, S&P Capital IQ, FERC, and industry websites were analyzed. The transaction data (for 43 transactions) presented in this report provide an illustrative view of recent investments to understand industry trends, which is based on publicly available information. The authors first reviewed recent projects developed within the medium-sized range over the last 10 years from ORNL data and supplemented it with data from Infralogic, S&P, FERC, and industry websites to add investments made in acquisitions and PE investments in corporations. The combined dataset illustrates the trends in recent transactions to better define the active investment landscape.

Data were also analyzed from the National Hydropower Association (NHA), U.S. Army Corps of Engineers (USACE), DOE, and the national laboratories to understand industry and investment sentiment, current activity, challenges, and opportunities.

1.3 Organization of the Report

This report includes the following sections:

- **Section 1** introduces the report and clarifies the purpose, scope, methodology, and organizing framework for the report.
- **Section 2** introduces the U.S. hydropower and PSH market.
- **Section 3** reviews compensation opportunities for medium-sized hydropower.
- **Section 4** presents the investment needs, challenges, and risks in the project life cycle.
- **Section 5** shows the investment landscape of the market broken down by investor type.
- **Section 6** outlines the greatest opportunities for market support, particularly by WPTO.
- **Section 7** concludes the report and offers next steps.

2 Introduction to the U.S. Medium-Sized Hydropower and Pumped Storage Hydropower Market

2.1 Existing Hydropower Facility Landscape

Low-impact hydropower and PSH provide firm clean energy capacity that the grid needs, particularly in high-renewable penetration scenarios (Sumner et al. 2023). This section of the report examines historic deployments and projected deployments of medium-sized hydropower and PSH projects to identify investment opportunities.

Renewable energy generation in the United States has grown to account for 20% of the overall generation mix (U.S. Energy Information Administration [EIA] 2023b). Hydropower accounts for 28.7% of the national renewable energy portfolio and represents 6.2% of the United States' overall electricity production. PSH accounts for 96% of utility-scale energy storage capacity and 70% power storage capacity (Uría-Martínez and Johnson 2023). However, as Figure 1 shows, unlike other renewables, growth in hydropower generation has declined since the 1980s.

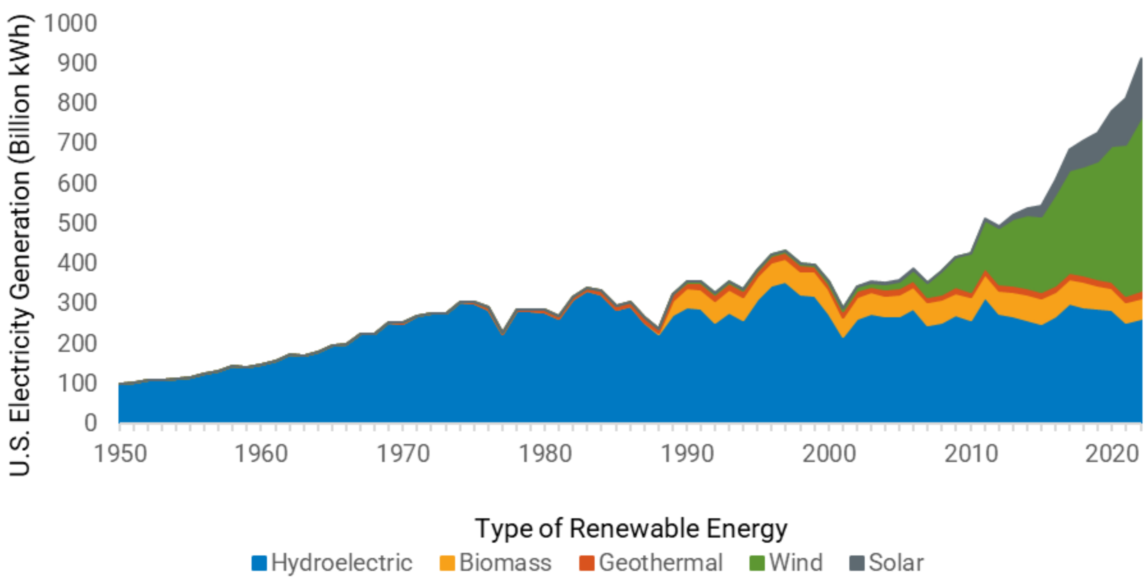

Figure 1. U.S. electricity generation from renewable energy sources, 1950–2022.

Source: EIA (2023c)

Large facilities (more than 30 MW in size) dominate the existing hydropower and PSH fleet, accounting for 92% of the existing fleet's total capacity (Johnson, Kao, and Uría-Martínez 2023). While hydropower development in the United States dates back to 1889, many of the nation's large dams were built in the 1930s through 1940s to support economic development and rural electrification; growth continued until the 1960s (DOE 2016). Many of the projects were federally built, such as through the U.S. Bureau of Reclamation ("Reclamation") or the Tennessee Valley Authority. Today, Congress authorizes three federal agencies to own and operate hydropower plants: USACE, Reclamation, and the Tennessee Valley Authority. These three agencies account for 49% of the total installed capacity. Privately owned plants account for only 25% of installed capacity (DOE 2016).

Today, the fleet has 12 facilities with greater than 1 GW installed capacity. Few very large resources like these remain available today that are suitable for large hydropower facilities and that investors would be interested in developing (Johnson, Kao, and Uría-Martínez 2023). Further, since development in the early 1900s, the environmental and community impacts are much better known, understood, and regulated (DOE 2016).

While large facilities account for significant installed capacity, medium-sized hydropower and PSH facilities, which currently represent 6 GW of installed capacity, or 6% of total hydropower capacity (Johnson, Kao, and Uría-Martínez 2023),[10] offer benefits, including:

- Potential for lower environmental impacts[11] (compared to larger hydropower facilities) because of their size and scale, and the possibility to develop on predeveloped sites, such as on existing non-powered dams (NPDs) and in conduits like irrigation channels and canals
- Opportunity for developing close to load centers to minimize transmission challenges
- Potential for developing on private facilities to support corporate climate goals
- Availability of hydropower resources, particularly through new technologies.

Despite this potential, construction of medium-sized hydropower facilities[12] has declined since the boom of the 1980s, as shown in Figure 2. That boom occurred as Congress relaxed regulations on hydropower due to the lack of oil supplies in the 1970s. Given the environmental concerns from increased hydropower activity, many regulations were reinstated in the 1980s (Levine et al. 2021). On average, 1.2 facilities were commissioned annually from 2000 to 2022, compared to 10.2 facilities per year from 1980 to 1989 and 4.0 per year from 1990 to 1999, according to ORNL data (Johnson, Kao, and Uría-Martínez 2023).

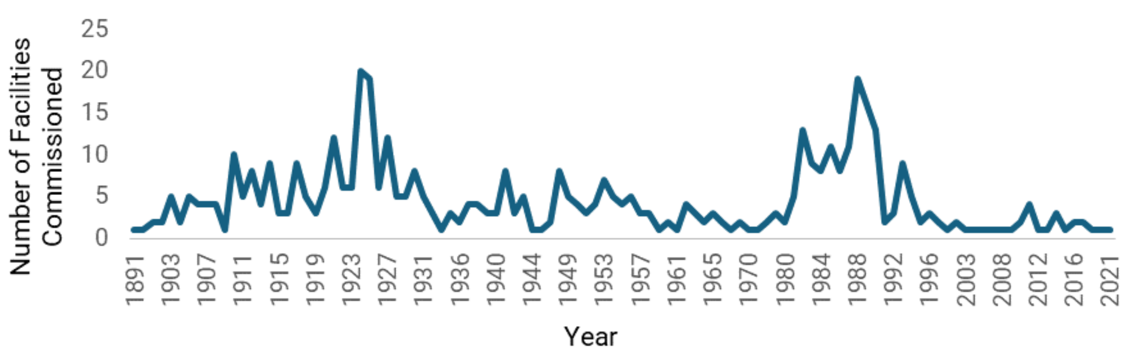

Figure 2. Number of facilities commissioned per year from 1891 to 2022 for medium-sized hydropower, excluding PSH.

Data source: Johnson, Kao, and Uría-Martínez (2023)

[10] Of the medium-sized hydropower and PSH facilities, PSH accounts for 1% of capacity (76 MW).
[11] Some medium-sized projects qualify as low impact per FERC regulations (FERC 2023e) and Low Impact Hydropower Institute criteria: https://www.hydro.org/powerhouse/article/certifying-hydropower-as-low-impact/.
[12] This downward trend applies to conventional hydropower, not PSH. Since only five medium-sized PSH facilities were commissioned from 1891 to 2022, there are no statistically significant trends in PSH development over time.

Due to its potential impact on water quality, species, cultural resources, and recreation, hydropower is highly regulated across 11 federal agencies as well as state and local agencies (Levine et al. 2021). FERC has primary oversight of hydropower and issues three types of authorizations: preliminary permits, licenses, and exemptions. Developers must also secure permits from other agencies, depending on location and land ownership, including USACE, the U.S. Department of the Interior's Bureau of Land Management, Reclamation, U.S. Forest Service, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (NOAA) Fisheries, various state agencies, and Indian Tribes (FERC 2017).

2.2 Medium-Sized Project Development Pipeline and Potential

The current medium-sized hydropower pipeline, including PSH, represents just over 1 GW of potential added capacity (Johnson, Kao, and Uría-Martínez 2023). Figure 3 illustrates the development pipeline by type of project. NPDs represent approximately 670 MW of potential capacity and more than 63% of capacity in the pipeline. Conduits have few facilities within this size range, but the opportunity for conduit development below the 5-MW medium-sized category (Johnson, Kao, and Uría-Martínez 2023) is significant.

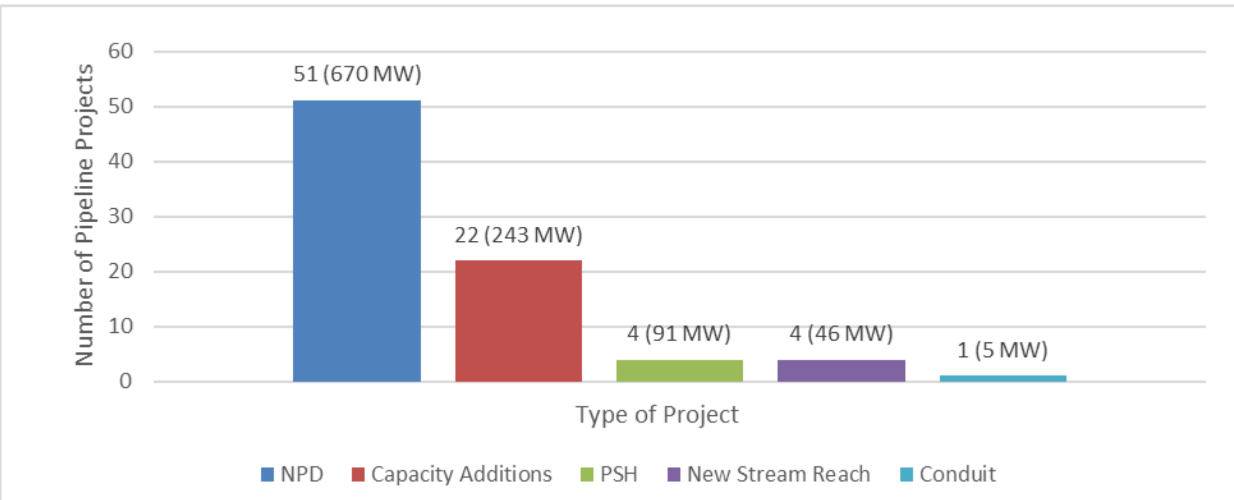

Figure 3. Number of medium-sized pipeline projects by type (82 projects totaling 1,056 MW).

Data source: Johnson, Kao, and Uría-Martínez (2023)

Of the 60 new projects in the permitting or licensing queue (i.e., excluding capacity additions), private non-utility developers own 57 projects (762 MW). The other three developers are a cooperative (24 MW), a municipality (18 MW), and a public subdivision (9 MW). Half of the 60 new projects are still in the permitting phase (Johnson, Kao, and Uría-Martínez 2023). The following subsections explore specific conditions for each project type that may make it more or less favorable for development.

2.2.1 Non-Powered Dams

Adding power generation equipment to NPDs appears to be the greatest potential for hydropower development, at least in the near term, out of all project types, representing 63% of the projects in the licensing process by capacity (Johnson, Kao, and Uría-Martínez 2023). In 2012, ORNL identified 204 dams in the 5–30-MW range for potential development with a total capacity of more than 2.6 GW (Hadjerioua, Wei, and Kao 2012). While NPDs benefit from avoiding the costly process of building a dam or reservoir, these projects face challenges optimizing a generation strategy that can uphold the existing water resource management requirements. As most sites were originally developed for specific water management purposes different than hydropower, developers typically need to preserve the existing water resource use when installing generating components in an NPD project (Oladosu, George, and Wells 2021).

Some of the non-federally owned projects that are less than 10 MW can qualify for an exemption[13] to FERC licensing processes (FERC 2023b). For USACE-owned dams, developers must receive Section 408 permission from USACE in addition to the FERC license, regardless of the project's capacity. Reclamation has a separate permitting process for Reclamation-owned dams; they issue a Lease of Power Privilege for private development using Reclamation-owned assets. States and local governments also require a Clean Water Act Section 401 Water Quality Certification or waiver thereof (Uría-Martínez and Johnson 2023).

> **Case Study: Successful Powering of an NPD—Red Rock Hydroelectric Project**
>
> The Red Rock Hydroelectric Project, commissioned in 2020, can serve as a potential roadmap for NPD projects across the United States. The dam was originally constructed by the USACE in 1969 for flood control, but it was recently powered by the developer Missouri River Energy Services, a 61-member organization of municipalities spread across Iowa, Minnesota, North Dakota, and South Dakota. Western Minnesota Municipal Power Agency financed the $400 million project and maintains ownership (USACE 2021).
>
> Design work for the 36.4-MW (Heller 2021) project began in 2011, and construction began in 2014. Construction of this run-of-release[14] plant took more than 6 years due to a number of technical and engineering challenges (Larson 2021). The project was one of Power Magazine's 2021 top plant award winners because it showed the potential of building clean energy projects on existing assets.

2.2.2 Capacity Additions

Capacity additions to existing facilities account for 23% (243 MW of 1,056 MW) of medium-sized hydropower and PSH projects in the pipeline by capacity. These projects usually imply capacity upgrades or new turbine units (Uría-Martínez and Johnson 2023) and can increase the facility's capacity, flexibility, and reliability. FERC approval is necessary for upgrades to nonfederal facilities. For capacity additions resulting in a 15% or greater increase to the maximum hydraulic capacity and 2 MW or greater increase to the installed nameplate capacity, developers must seek capacity amendments or account for the increase in relicensing processes. For smaller changes in capacity, developers instead must file a non-capacity amendment or convert a license to an exemption (Levine, Curtis, and Kazerooni 2017).

[13] Small hydropower projects, which are 10 MW or less, that will be built at an existing dam, or projects that utilize a natural water feature for head or an existing project that has a capacity of 10 MW or less and proposes to increase capacity.

[14] Run-of-release hydroelectricity describes a generation technique in which inflow and outflow of the dam are carefully managed because of external variables, such as flood control or drinking water availability. In this case, USACE mandated a run-of-release project to avoid impacting flood control operations in the area (Larson 2021).

2.2.3 Pumped Storage Hydropower

PSH, a type of long-duration and fast response hydropower energy storage, is the primary form of storage capacity in the United States and an important enabler for variable renewable energy (VRE) integration. However, PSH facilities require specific topographical conditions to construct lower elevation and upper elevation reservoirs. Most of these facilities have significant energy storage capacity (more than 30 megawatt-hours [MWh]). Closed-loop projects, which allow for greater siting flexibility and typically have lower environmental impact, account for 80% of the total PSH projects in the development pipeline (including all sizes). From 2019 to 2022, the number of PSH projects in the development pipeline increased from 67 to 96 projects (including all sizes). All active facilities today are open loop.[15] Additionally, most projects in the pipeline have storage durations that range from 8 to 12 hours, compared to the median 2-hour-duration storage of existing utility-scale batteries (Uría-Martínez and Johnson 2023). Long-duration energy storage technologies, such as PSH, may qualify for capacity payments in wholesale markets (where applicable).[16]

Using potential reservoir sites identified in DOE-sponsored research, the National Renewable Energy Laboratory (NREL) estimates that a total of 3.5 terawatts of closed-loop technical potential capacity exists across 14,846 sites when assuming a 10-hour storage duration (Rosenlieb, Heimiller, and Cohen 2022). At the end of 2022, only 10 of the 96 PSH projects in the development pipeline of all sizes had advanced beyond the feasibility evaluation stage. Of those projects, FERC had issued a license to only three, and none had begun construction (Uría-Martínez and Johnson 2023).

While PSH is not a new technology, new innovations are occurring, creating opportunities to reduce time, costs, and risks of developing PSH projects. Additionally, innovations may increase the number of suitable sites for PSH, enabling greater opportunity for long-duration storage and additional hybrid applications. As with any new technology, commercial viability may not yet be known. Examples of new applications include (Koritarov et al. 2022):

- **Submersible pump-turbines and motor-generators:** This type of technology, from Obermeyer Hydro, Inc., removes the need for a separate power equipment housing structure (i.e., powerhouse). One important innovation is in the reversible pump-turbine flow inverter to redirect the water flow so that it enters and exits the well. This technology could decrease PSH’s footprint and enable installation at existing hydropower facilities while decreasing risks and uncertainty of building an underground powerhouse.
- **Geomechanical PSH:** Quidnet Energy is developing a new technology that pumps water into the ground between rocks where it is stored under pressure. The natural pressure of rock formations acts like a spring to pass water through a hydroelectric turbine to generate electricity. Quidnet claims this technology has an energy storage duration of 10 hours or longer and is modular (units are 1 to 10 MW), scalable, and minimizes the need

[15] Open-loop PSH describes projects with either an upper or lower reservoir that is continuously connected to a naturally flowing water source such as a river. In comparison, a closed-loop PSH system is an “off-river” site that produces power from water pumped to an upper reservoir without a significant natural inflow.
[16] Capacity and wholesale markets are further discussed in Section 3.

for two reservoirs and hilly terrain. Using techniques from the oil and gas sector, Quidnet envisions quickly drilling wells.

- **Open pit mine:** Mines present an opportunity to redevelop existing infrastructure, creating reductions in cost and time to development, as well as potential environmental and community benefits from redevelopment. There is one such site in the United Kingdom and two projects in development, one in Australia and another in the United States. This technology uses existing mine pits for the upper and lower reservoirs.

2.2.4 New Stream-Reach Developments

New stream-reach development, which describes new projects installed through undeveloped streams (centered in Alaska and Oregon), tend to have the greatest barriers to development today and are not likely to have a strong future impact on the pipeline outside of the Northwest and Alaska. To minimize impacts, most projects divert flow to a powerhouse rather than developing an impound dam. A 2014 DOE study that identified potential sites for new stream-reach development found that many sites have a head of less than 25 feet (Kao et al. 2014). These "low-head" facilities have a higher cost per unit power and a less efficient turbine, making these projects typically less viable. The same study found more than 65.5 GW of new resource capacity available at all size developments across the country, when excluding areas where federal legislation limits development (Kao et al. 2014).

2.2.5 Conduit

Conduit projects that add power generation capacity to existing human-made canals or irrigation channels represent the smallest portion of projects seeking licenses in the medium-size category. However, there are additional projects with capacity of less than 5 MW in development (Uría-Martínez and Johnson 2023). These projects may have notably lower impact on the environment than other project types. Additionally, they qualify for net metering in many states, adding an additional revenue stream for on-site generation at facilities with high power demand. These facilities may have more favorable project development timelines through the expedited 45-day regulatory approval process for qualifying conduit projects created by the Hydropower Regulatory Efficiency Act of 2013 and its amendments in America's Water Infrastructure Act of 2018,[17] as well as the streamlined Reclamation lease power privilege authorizations for small conduit hydropower development from the Small Conduit Hydropower Development and Rural Jobs Act of 2013 (PL 113-24) (Kao et al. 2022). Further, a recent DOE ORNL report found opportunities to develop hydropower on conduits in every state, which could add 1.41 GW of new capacity and 620 MW within the 5–30 MW range (Kao et al. 2022).

[17] Passed in 2018, America's Water Infrastructure Act aimed to improve public health and quality of life through infrastructure investments that improve drinking water and water quality. Activities directed by this legislation include establishing a state drinking water revolving fund, assessing community water system risk and resilience, providing funding for water infrastructure programs through grants, and more (U.S. Environmental Protection Agency 2023). For more information on America's Water Infrastructure Act, visit epa.gov.

Case Study: Innovative Design and Approach to Monetizing Canal Infrastructure

Emrgy Inc. is a technology company that designs and installs modular turbines (10–40 kilowatts [kW]) for use on canals, allowing asset owners to monetize existing water infrastructure. Emrgy's modular design aims to reduce costs, decrease timelines, and increase flexibility. According to Emrgy's website, their model does not require the same hydraulic head as conventional hydropower, which should enable flexible geographic deployment (Emrgy 2023). By targeting agricultural or municipal customers with existing canal infrastructure, Emrgy aims to reduce offtake risk through established partnerships with direct buyers and reduce permitting risks by taking advantage of the conduit rules noted in Section 2.2.5. Emrgy turbines have been purchased and installed by Denver Water, Davis and Weber Counties Canal Company, Oakdale Irrigation District, and others (Greentechlead 2023). As of April 2023, Emrgy raised $18.4 million in Series A funding from Oval Park Capital, Fifth Wall, Blitzscaling Ventures, Overlay Capital, and Veriten (Business Wire 2023). Emrgy plans to use these venture funds to open an assembly facility in Colorado (Associated Press 2023).

2.2.6 Hybrid Projects

Hybrid-plant configurations, defined as plants that involve two or more types of generation units or a generator and a battery paired at a single connection point, are an emerging development trend (Uría-Martínez and Johnson 2023).[18] While these plants have operated for years, pairing hydropower with batteries is increasingly popular, particularly in the medium-size range. Lawrence Berkeley National Laboratory counts five active projects as of 2021, as well as six hydropower plants that plan to add batteries as part of the interconnection queues. These projects can "access new revenue streams by providing peaking power or ancillary services, such as frequency regulation or black start" (Uría-Martínez and Johnson 2023). In addition to unlocking economic benefits, these projects can provide environmental outcomes through the ability to operate hydropower systems differently to manage potential environmental constraints as well as support regulatory requirements (Bellgraph et al. 2021). AES Corporation, an IPP, is developing the West Kauai Energy Project in Hawaii, a 24-MW PSH facility coupled with a 35-MW solar array and 240-MWh battery storage for dispatch during evening peak hours (Walton 2021). The West Kauai Energy Project has not started construction but has a tentative commissioning date for 2024. This is one of a few PSH projects of its size in the pipeline.

2.2.7 Future Opportunity in Hydropower Development

Within the medium-size category, there are opportunities for development from technology enhancements and a minimized regulatory burden. Figure 4 highlights these opportunities.

[18] This project type was referred to as "combined projects" for the purposes of the stakeholder survey.

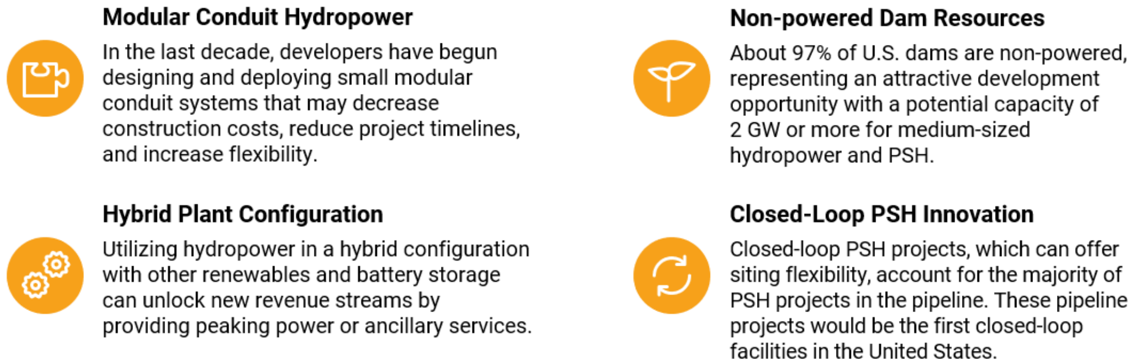

Figure 4. Medium-sized hydropower opportunity highlights

2.3 Investment Opportunity in Hydropower

Building the current medium-sized hydropower and PSH pipeline requires significant investment. Based on capital cost data from 80% of hydropower projects since 1980—which ranged in cost from $3,000/kW to $9,000/kW[19] (data on per-kilowatt costs from Uría-Martínez and Johnson [2023])—realizing the current 1,056-MW medium-sized project pipeline (referenced in Figure 3) would require at least $3.16 billion to $9.5 billion of investment. The current medium-sized pipeline is equivalent to 17% of installed capacity at existing medium-sized hydropower and PSH facilities, which total 6 GW of capacity (Johnson, Kao, and Uría-Martínez 2023).

2.3.1 Investor Sentiment

Investors indicate an overall low interest in investing in medium-sized hydropower, albeit increasing with time, with the most interest being in capacity additions and closed-loop PSH, as shown in Figure 5 and Figure 6. Of the 36 survey respondents, 14 were utilities, and most of this respondent type showed a preference for capacity additions relative to other project types. Most commercial banks and institutional investors surveyed were technology-agnostic, which could suggest that other factors beyond hydropower technology type drive their investment decisions. While the majority of these respondents had not invested in medium-sized hydropower in the past 5 years, most replied that they would consider investing in this size of hydropower project in the future.[20]

[19] This estimate does not take into consideration current investment in the pipeline and is an estimate using capital cost ranges only.
[20] In the survey, combined projects were defined as: "e.g., solar coupled with a hydropower dam" and are similar to and synonymous with hybrid projects described earlier.

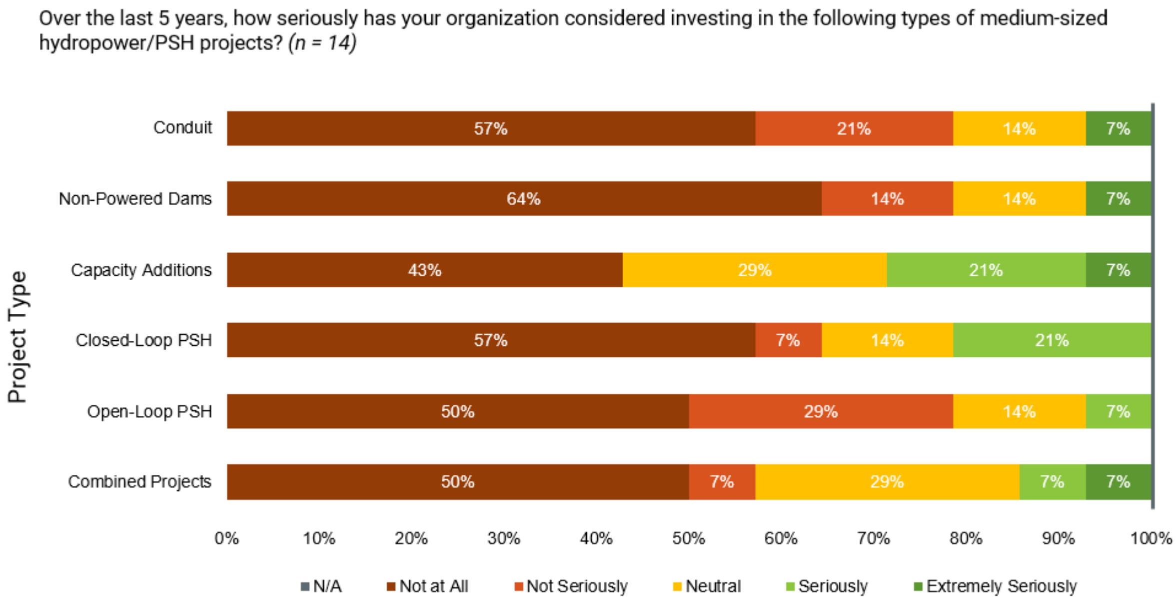

Figure 5. Investor sentiment on past investments by project type

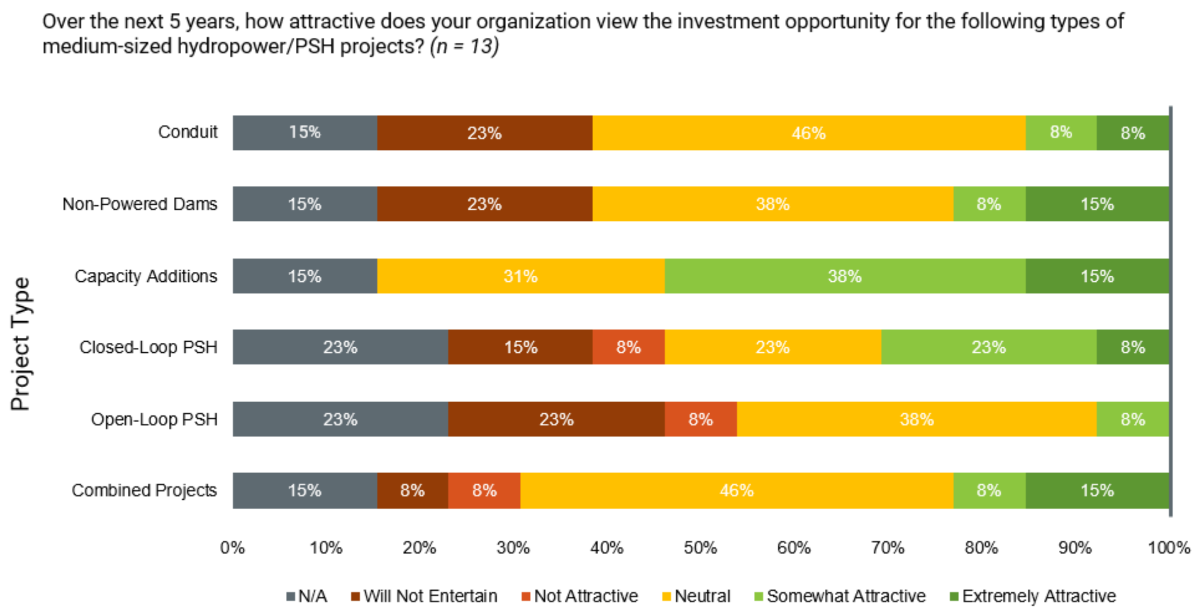

Figure 6. Future investor sentiment by project type

The developer-specific survey results are more optimistic about hydropower and PSH opportunities across project types compared to the commercial banks and institutional investors surveyed. While showing similar levels of interest as commercial banks and institutional investors in capacity additions and closed-loop PSH, developers demonstrate much greater interest in developing conduits, NPDs, and combined projects than investors expressed in financing them. However, this is representative of the current hydropower market, where developers and IPPs are driving the market and initial development and investment to advance projects to an "investable stage" (i.e., when projects are ready for construction). Stakeholder interviews also indicate that there is less developer interest in new stream-reach development projects. Figure 7 presents developers' views on future hydropower development opportunities, based on project type, of those who intend to develop medium-sized hydropower.

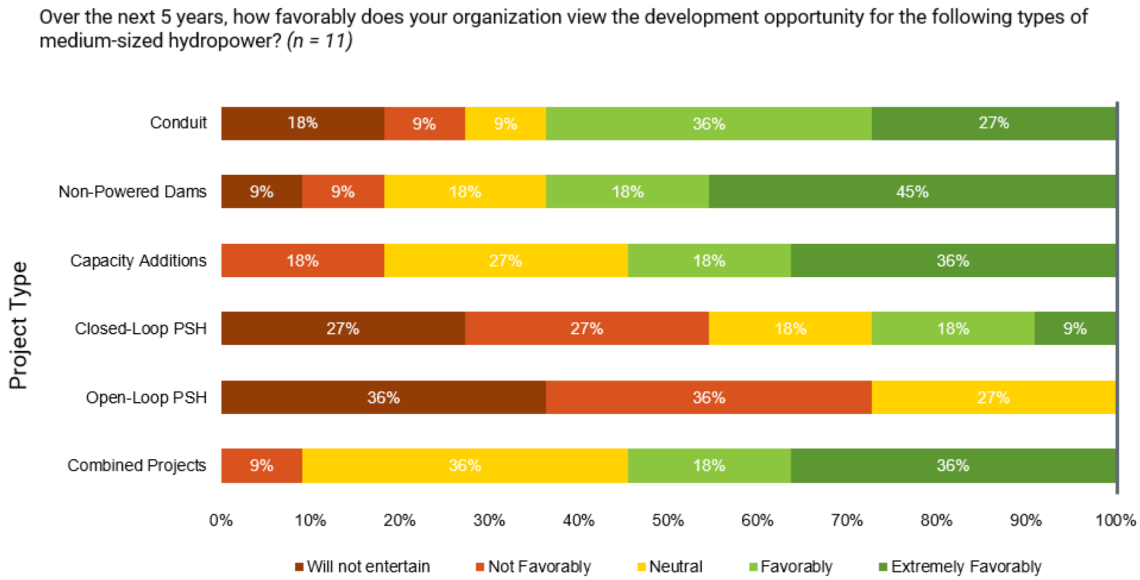

Figure 7. Developers' future development intentions by project type

3 Compensation Mechanisms and Regional Market Structures for Hydropower and PSH

The organization of the electricity sector will influence the type of revenue opportunities that may be available for hydropower and PSH projects. Figure 8 provides an overview of the U.S. wholesale electricity markets. The United States has two primary market structures: vertically integrated and restructured. Vertically integrated wholesale electricity markets exist primarily in the Northwest, Southeast, and Southwest and include federal systems, such as the Bonneville Power Administration, Tennessee Valley Authority, and the Western Area Power Administration. Restructured wholesale electricity markets are typically administered through regional transmission organizations (RTOs) or independent system operators (ISOs). Vertically integrated markets can also be administered by RTOs/ISOs.[21] They include the California ISO (CAISO), Electric Reliability Council of Texas (ERCOT), ISO New England (ISO-NE), Midcontinent ISO (MISO), New York ISO (NYISO), Pennsylvania-New Jersey-Maryland Interconnection (PJM), and Southwest Power Pool (SPP).[22] Except for Texas, FERC regulates wholesale market operations and transactions throughout the contiguous United States (PJM 2023a).[23]

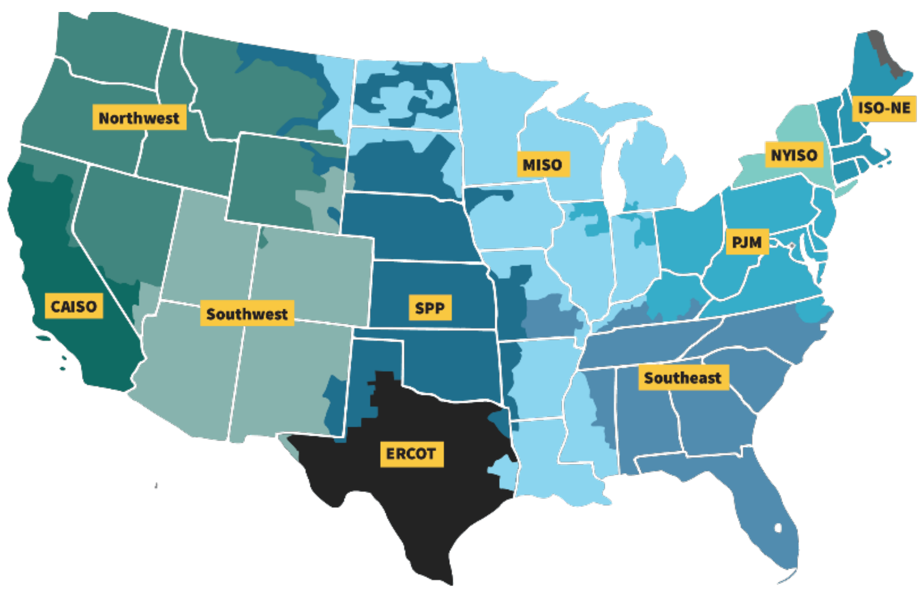

Figure 8. Wholesale markets in the United States.

Source: FERC 2023a

[21] RTOs and ISOs manage the operation of the electrical grid and administer competitive wholesale markets. The only difference is the geographic area they cover. An RTO is a multistate system operator, such as PJM, MISO, SPP, and ISO NE; an ISO is a single-state operator, such as CAISO, ERCOT, and NYISO.

[22] More information about U.S. wholesale markets is available at FERC's website at https://www.ferc.gov/electric-power-markets.

[23] All ISOs/RTOs, except ERCOT, are under FERC jurisdiction. The Public Utility Commission of Texas regulates ERCOT.

The following sections provide details about compensation mechanisms starting with vertically integrated markets in Section 3.1 and restructured competitive markets in Section 3.2. Tax credits, as a potential revenue stream, are covered in Section 6.1.1.

3.1 Compensation Mechanisms in Vertically Integrated Electricity Markets

Vertically integrated markets are those in which a single utility or entity typically has a monopoly on electricity generation, transmission, and distribution. In these markets, prices and services are subject to oversight and control by government agencies or regulatory authorities with a goal to promote stability and uniform service. In vertically integrated states, the power generation capacity is procured by electric utilities through integrated resource plans. The integrated resource plan process is vertically integrated through states' public utility commissions. It typically incorporates certain least-cost resource standards to ensure the utility is investing in cost-effective generation resources with a reasonable rate of return. Once the utility's regulator approves a generation investment, the utility recovers its investment through retail ratepayers. Subject to regulatory approval, utilities can also procure supply through power purchase agreements (PPAs) (Section 3.3.1), other contractual arrangements, and/or balancing markets, e.g., the Western Energy Imbalance Market (Western Energy Imbalance Market 2023). There may be other federal or state laws that influence the composition of the integrated resource plans, such as greenhouse gas emissions reduction requirements, renewable portfolio standards (RPSs), Public Utility Regulatory Policies Act (PURPA) Qualified Facilities,[24] and more. The key feature in vertically integrated markets is that generation investments are guaranteed a certain level of revenue recovery by captive ratepayers. Therefore, there is little economic risk for these projects. However, these projects must meet regulatory-driven least-cost requirements to be included in integrated resource plans that establish the utility's revenue requirements.

3.2 Compensation Mechanisms in Restructured Competitive Markets

Unlike vertically integrated states with integrated resource planning, restructured states rely on competitive markets to deliver least-cost resources. These regions differ from vertical markets in that developers typically choose the plant size and location of new generation investments. Once built, generation resources in restructured regions earn revenues through various markets, including capacity, energy, and ancillary service markets and through PPAs (see Section 3.3.1). Certain regional transmission projects are planned by the RTO/ISOs and overseen by FERC, while distribution system planning and retail policies remain under state jurisdiction. Most states in PJM and ISO-NE are restructured, while most states in MISO and SPP are vertically integrated. Generators in vertically integrated states can be dispatched based on least cost by RTO/ISOs but are not fully exposed to market risk given cost recovery by captive ratepayers.

Table 1 shows a comparison between services and compensation available to hydropower in different markets.

[24] More information about PURPA Qualified Facilities is available at FERC's website at https://www.ferc.gov/qf.

Table 1. Summary of Potential Services and Compensation (by Region) for Hydropower and PSH

ISO/RTO	Energy Market	Ancillary Services	Black-Start Services	Capacity Market	Voltage and Reactive Power
Compensation	Locational Marginal Price (LMP)/ Extended LMP[25]	Market Clearing Price	Contract-Based	LMP	Arranged
CAISO	✓[26]	✓[a]	✓[b]	Compensation for capacity is included in resource adequacy requirement	✓
ERCOT	✓[c]	✓[d]	✓[e]	Compensation for resource adequacy is included in energy market	✓
ISO-NE	✓[f]	✓[f]	✓	✓[f]	✓
MISO	✓	Hydropower[27]	✓	✓[28]	✓
NYISO	✓[a]	✓[a]	✓[a]	✓[a]	✓
PJM	✓[a]	✓[a]	✓	✓[a]	✓
SPP	✓[a]	✓[a]	✓[a]	No market	✓

Sources: [a]McAlister and Ramadevanahalli (2019); [b]CAISO (n.d.); [c] ERCOT (2019); [d] ERCOT (2023); [e] ERCOT (2022); [f] ISO New England (n.d.)

Figure 9 compares average annual capacity, energy, and ancillary market prices per MWh, across all seven RTOs/ISOs in 2021 and 2022. The figure shows that on a per MWh basis, most system costs recognized today are from energy markets (Potomac Economics 2023). MISO has lower overall prices due to low natural gas prices and weak shortage pricing. ERCOT lacks a capacity market but has strong shortage pricing. In 2021, ERCOT had extremely high market prices largely because of the effects of Winter Storm Uri. NYISO price increases were caused by increasing natural gas prices, cold weather experienced around the end of the year in 2022 that led to real-time market price volatility, and increased transmission congestion. ISO-NE's high-capacity prices resulted from over-forecasted load and high energy prices influenced by constrained gas pipelines. In 2022, SPP prices increased mostly due to an increase in natural gas prices (Potomac Economics 2023). In CAISO, the factors contributing to the all-in price increase included natural gas prices, peak load, and cost of imported energy (Hildebrandt et al. 2023). In summary, market prices can vary by region but most prices are driven by energy market costs,

[25] Applies to all ISOs/RTOs except for MISO, which uses an extended LMP method (Section 3.2.3) of compensation.
[26] CAISO compensates pumped storage hydropower differently.
[27] MISO does not allow dispatchable intermittent resources and intermittent resources to provide spinning, supplemental, or short-term reserve.
[28] Energy storage resources that qualify as use-limited capacity resources are required to offer 4 or more hours of nameplate capacity storage.

and the prices of electricity can fluctuate due to various factors. Power plant owners, including hydropower and PSH, are exposed to the risk of price fluctuations and must assess and manage these risks to ensure the sustainability and success of their operations in competitive energy markets.

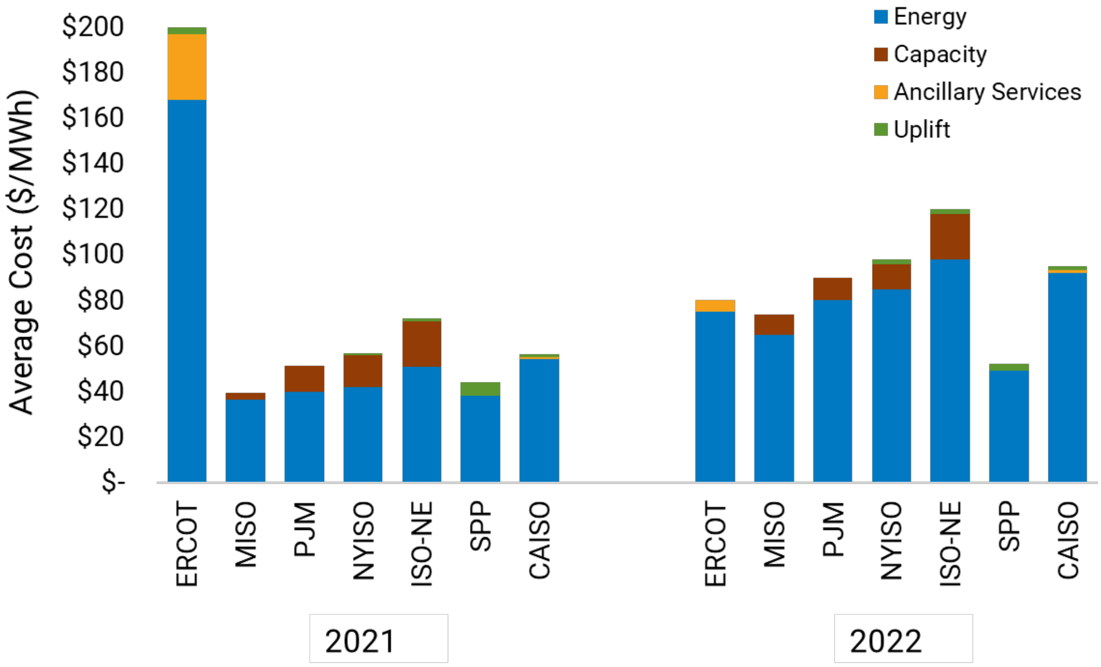

Figure 9. Cross-market all-in price comparison.

Average costs are approximate. Small average cost values that would not be visible on the chart are not included. Data Source: Potomac Economics (2023), Hildebrandt et al. (2023).

A challenge in assessing investment opportunities in markets is the question of whether current prices are indicative of future prices. For example, all things equal, as thermal resources retire and reserve margins decrease capacity, prices are expected to increase, sending price signals for new capacity investments. However, what is not clear is by how much prices will change and in what timeframe, given prices near $0/kW-yr in some areas today, highly volatile in others (ranging between $1/kW-yr and $86/kW-yr recently in MISO), and projected to exceed $150/kW-yr in several forward-looking, high-renewables scenarios (Gagnon et al. 2023). The implications of this are discussed in Section 3.2.3.

Given the role that market structures have in determining project feasibility, the investment survey asked developers how favorably their organization viewed each of the seven ISOs/RTOs for development of medium-sized hydropower. Figure 10 shows the summary of responses.

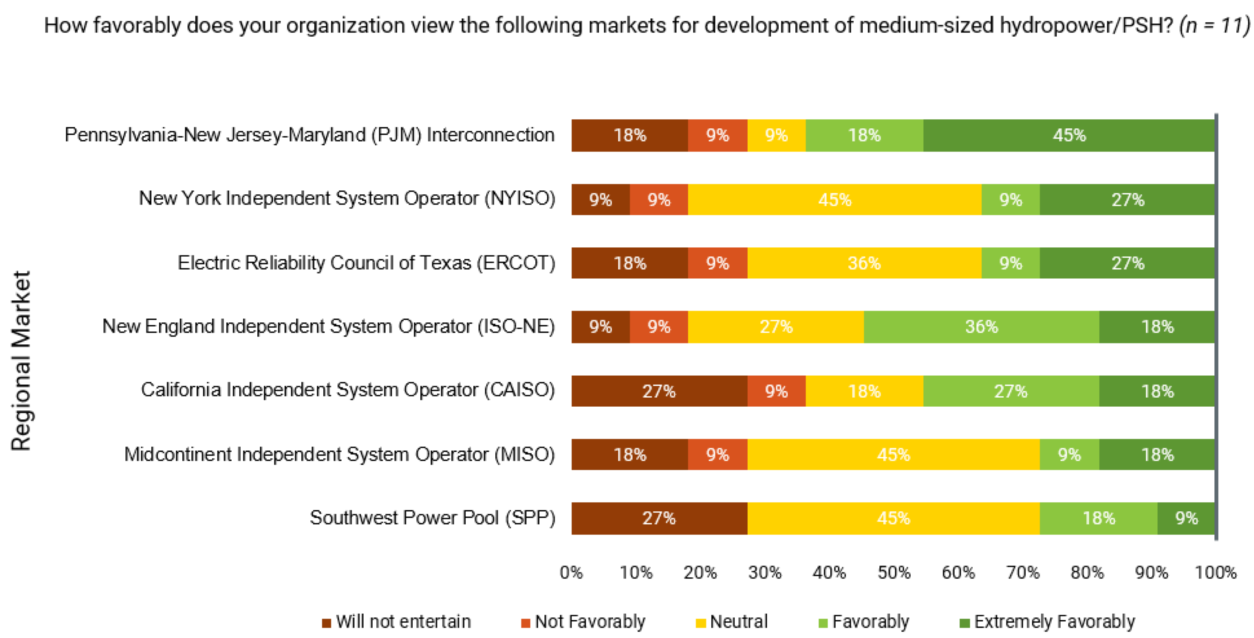

Figure 10. Developer preferences by regional market

Survey results suggest that PJM is perceived as the most favorable ISO/RTO in which to develop hydropower, with 63% of respondents noting PJM favorably or extremely favorably. Many states in the PJM network include hydropower as a qualified resource for renewable energy certificates (RECs), and PJM has a capacity market with transparent forward prices. These factors likely contribute to the positive perception developers have of PJM. Individual developers showed variation in their sentiments among the different regional markets (e.g., a developer viewed MISO extremely favorably, SPP neutrally, and PJM favorably). Given the dispersion of results, this seems to indicate that developers consider regional markets at least somewhat in their development decisions.

3.2.1 Merchant Power Plants

A purely merchant generator is a plant that does not have utility or energy sales contracts and earns revenue only from sales into the restructured competitive markets (FERC 2023d; American Public Power Association 2023). In practice, few plants are built on a purely merchant basis. PPAs lower investor risk by securing more stable cash flows, but better market pricing for the output of merchant plants can also spur investments even when it is difficult to secure a PPA. Developers might be able to secure more funding if merchant hydropower producers had a larger number of revenue streams that valued hydropower as a reliability resource as well as a power producer. However, the technologies in question must meet market eligibility requirements to qualify. Hydropower producers participating in ISOs/RTOs or other markets (e.g., Western Energy Imbalance Market) can provide additional services beyond the energy market to increase profitability. The following sections further discuss the various power and services that hydropower plants can provide in competitive wholesale markets.

3.2.2 Energy and Operating Reserve Market

Revenue from the energy and operating reserve market is the most conventional revenue stream for power plants operating in competitive markets. RTOs/ISOs operate two-settlement markets that consist of a day-ahead and a real-time energy and operating reserve market. The day-ahead market is a forward market where RTOs/ISOs calculate the hourly locational marginal price (LMP) “for the next day based on the amount of energy generators offered to produce, the amount of energy needed by consumers, and scheduled transactions between buyers and sellers of energy” (PJM 2023d). The real-time market is a spot market where RTOs/ISOs calculate LMP at short intervals (typically 5-minute intervals[29]) based on actual grid operating conditions. Dispatchable hydropower and PSH are well suited to participate in both. The day-ahead market schedules generation resources to meet the next-day forecasted demand, and the real-time market adjusts for differences between resources scheduled in the day-ahead market and actual power generation and demand. Flexible generation sources, like dispatchable hydropower and PSH, are ideal for providing this type of energy (Newell et al. 2021). When the run-of-river hydropower production forecast has low confidence, the real-time market may be the developer’s preference so the unit receives something for its generation without the risk of committed volumes in the day-ahead market.

Case Study: PJM Market Price Risk

The 2021 and 2022 price differences in PJM, shown in Table 2 (PJM 2023d), illustrate that the all-in electricity prices in wholesale market fluctuates from year to year.

In 2021, the all-in electricity price would not be sufficient to recover the hydropower levelized cost of energy (LCOE). (EIA estimated the unweighted total system LCOE without tax credit to be $64.27/MWh for generators entering the service in 2027, expressed in 2021 dollars). In 2022, the compensation would be sufficient. Furthermore, PSH may not receive the full-capacity credit because the capacity compensation (in PJM) is based on the PSH duration.

Table 2. Prices for PJM Market Services (2021–2022)

Service ($/MWh)	Price 2021	2022
Energy Market	$39.78	$80.14
Capacity Market	$10.95	$8.03
(AS) Regulation	$0.19	$0.38
(AS) Reserve Syn	$0.07	$0.12
(AS) Sec Reserve	$0.00	$0.00
(AS) Reserve non-Syn	$0.02	($0.01)
(AS) DASR	$0.01	$0.01
(AS) Reactive	$0.48	$0.50
(AS) Black Start	$0.09	$0.09
(AS) Uplift Energy Uplift (Operating Reserves)	$0.23	$0.37

[29] Additionally, CAISO calculates LMPs at 15-minute intervals.

Hydropower exhibits a unique capability to provide energy and operating reserve because of its ability to quickly adjust its output in response to grid fluctuations. Unlike wind and solar, which depend on weather conditions and lack the instantaneous control of generation, hydropower's flexibility allows it to serve as a reliable source of reserve capacity, contributing to grid stability during sudden demand changes or unexpected supply disruptions.

Generation resources in the energy market are compensated based on their LMP, which includes marginal cost of energy, marginal cost of congestion, and marginal cost of losses.[30] Generation resources may receive a local price different from prices elsewhere in the system because the LMP reflects transmission congestion and losses in addition to energy price. In operating reserve markets, generation resources are compensated based on a market clearing price for specific services, such as regulation reserve, synchronized or spinning reserve, supplemental reserve, short-term reserve, and ramping capability. Hydropower as a generation resource can participate in these markets. PSH is considered an energy storage resource and can participate in the energy and regulation reserve market. Run-of-river hydropower can provide limited services because RTOs/ISOs consider it an intermittent resource that is only partially dispatchable. As such, it follows RTOs/ISOs rules for intermittent resources, such as wind and solar (MISO 2022).

MISO enhanced LMP and market clearing price calculations with extended LMP to allow certain fast-start and emergency operation resources to set prices. The fast-start resource does not include fuel-limited resources, such as PSH, electric storage resources, run-of-river hydropower, and wind resources. Online generation resources (including hydropower) that can be started, synchronized, and inject energy within 60 minutes of being notified and have a minimum run time of up to 1 hour are included (MISO 2023b). This mechanism seeks to better reflect the marginal cost of supplying energy and reduce out-of-market payments. In 2022, the average price effect of the extended LMP on MISO's real-time energy prices was $1.45/MWh (Potomac Economics 2023). Figure 11 shows that 36% of developers and 40% of investors surveyed responded that the introduction of extended LMP was likely or extremely likely to affect investment in hydropower and PSH.

[30] ERCOT LMP does not include the marginal losses component.

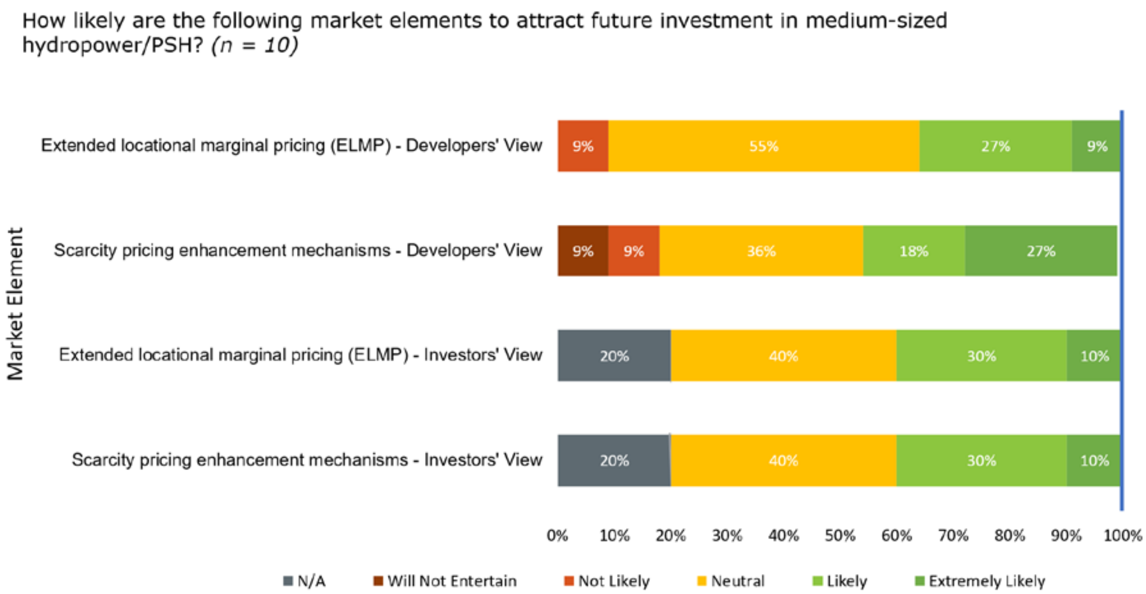

Figure 11. Developers' and investors' view of the ability of market-enabling support to create investment interest

Implementation of scarcity pricing varies across markets, but, in general, scarcity pricing reflects the scarce conditions that occur when energy and operating reserve requirements exceed available supply (MISO 2021). From 2015 to 2022, the ERCOT systemwide offer cap was $9,000/MWh while other systems had price caps of $1,000/MWh. Although ERCOT reduced the cap to $5,000/MWh in the wake of Winter Storm Uri in February 2021, it remains the highest among U.S. markets (Public Utility Commission of Texas 2023). Scarcity pricing provides a higher revenue potential to generators during a short time. However, hydropower and PSH owners should be aware that scarcity pricing is a rare event and may diminish as new resources are added to the system or parameters change prior to an event. Figure 11 shows that 45% of developers and 40% of investors surveyed responded that scarcity pricing enhancement mechanisms were likely or extremely likely to affect investment in hydropower and PSH.

3.2.3 Capacity Market and Resource Adequacy

Capacity markets are meant to ensure that the grid has an adequate amount of generation available to meet demand, plus a reserve margin to ensure reliability. PJM, MISO, NYISO, and ISO-NE have a capacity market. They all allow hydropower and PSH to participate if they pass a capacity test. For run-of-river, RTOs/ISOs typically calculate unforced capacity[31] separately for summer and winter capability periods. As an example, NYISO uses the 20 highest real-time load hours in each of the five previous capability periods to calculate the rolling average of the hourly net energy provided by each run-of-river hydropower plant (New York ISO 2023). For other hydropower and PSH, ISOs/RTOs use equivalent demand forced outage rates to calculate the unforced capacity.

[31] Unforced capacity "estimates the probability that a resource will be available to serve load, taking into account forced outages and forced deratings" (NYISO 2023).

RTOs/ISOs commonly use effective load-carrying capacity (ELCC) methodology to assign capacity rating and capacity accreditation to renewable resources based on their potential to provide firm capacity. PJM applies ELCC to variable (i.e., wind, solar, run-of-river hydropower without storage, and landfill gas units without an alternate fuel source), limited-duration (i.e., PSH, batteries, and generic limited duration resources), and combination (i.e., hybrid solar plus battery, hydropower with non-pumped storage, and other combinations of limited duration with unlimited or variable resources) resources (PJM 2023c). A PJM calculation of ELCC determined that PSH with 8- and 10-hour duration will receive 100%, 6-hour duration will receive 96%, hydropower with non-pumped storage will receive 94%, 4-hour duration will receive 80%, and run-of-river hydropower will receive 34% of the full capacity payment for 2025/2026 capacity auction (PJM 2023b). In California, the California Public Utilities Commission (CPUC) Mid-Term Reliability Decision (D.21-06-035) requires standardized ELCC for wind, solar, battery, and PSH resources. The latest calculated ELCC values are 86.6% (in 2025) to 92.7% (in 2028) for 12-hour PSH and 82.6% (in 2025) to 88.7% (in 2028) for 8-hour PSH (CPUC 2023). Furthermore, the ELCC of 8-hour PSH is 1.4% lower "than the ELCC of 8-hour battery storage due to its lower round-trip (charging and discharging) efficiency" (CPUC 2023). MISO uses ELCC for wind capacity credits and in seasonal accredited capacity to calculate solar and run-of-river hydropower capacity credit (MISO 2023b). Note that ELCC numbers for shorter-duration storage (e.g., 4- and 6-hour) are expected to decline as these markets become saturated (Stark, Dhulipala, and Brinkman 2023).

MISO calculates run-of-river hydropower seasonal accredited capacity as a median of up to 15 years of similar seasonal data. SPP uses ELCC only for wind and solar (SPP 2022), similar to ERCOT (Astrapé Consulting 2022); ISO-NE (GE 2022) and NYISO (Carkner 2023) are investigating use of ELCC for the capacity accreditation.

Thirty-six percent (36%) of developers (Figure 12) and 50% of investors (Figure 13) surveyed responded that the introduction of the ELCC methodology is likely or extremely likely to affect investment in hydropower and PSH.

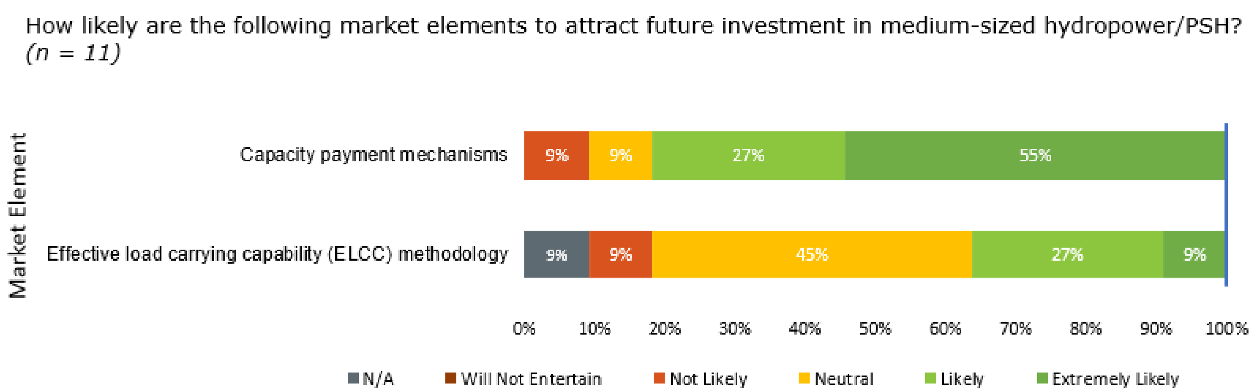

Figure 12. Developers' view of the ability of market enabling to create investment interest (capacity)

CAISO, ERCOT, and SPP do not have a capacity market.[32] Instead, CAISO and SPP procure capacity through their member states' IRP processes, and ERCOT uses scarcity pricing in the energy market to incent resource adequacy. Eighty-two percent (82%) of developers (Figure 12) and 70% of investors (Figure 13) surveyed responded that capacity payment mechanisms were likely or extremely likely to affect investment in hydropower and PSH.

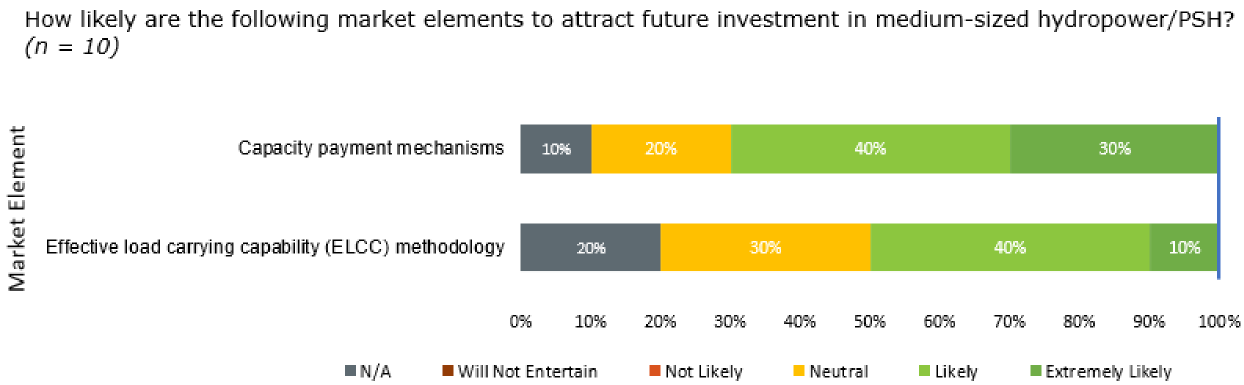

Figure 13. Investors' view of the ability of market enabling to create investment interest (capacity)

As mentioned in the beginning of this section, the uncertainty surrounding the value of capacity in future markets complicates the overall investment situation for all generators, including for hydropower. Hydropower is an excellent source of low-carbon capacity, a service not easily provided by wind and solar yet necessary to integrate variable renewable sources like wind and solar into the grid. Recent work (Stark and Brinkman 2023) projects that in a high-renewables grid, capacity payments may account for as much as half of hydropower's (and other dispatchable generation's) future revenues. While this sounds promising, consider this in light of the extreme volatility seen in the recent MISO seasonal auction where prices fell from a year-earlier price of $86/kW-yr to a price that at times was as low as $1/kW-yr. Some would argue that the markets worked as evidenced by participants responding accordingly (i.e., the year-earlier price incentivized the buildout of new generation). However, investors likely see the volatility in MISO's auctions differently. Even though the general consensus is that capacity payments will rise as we move toward a high-renewables system as capacity associated with fossil-based generation is retired, how and when are still very much in question. Consequently, although capacity revenue payments appear promising in the long term, capacity market price volatility is likely to dissuade rather than encourage investors, which complicates the investment landscape for a capacity-capable resource like hydropower (i.e., hydropower's capacity capabilities will likely be of high value sometime in the near future, but it is yet to be determined when that will occur and how difficult it will be to get there). This is a gap in current hydropower valuation methodology that would likely benefit from additional research.

[32] The Western Resource Adequacy Program, which is developing in the Western Interconnection, facilitates capacity sharing among certain participating states.

3.2.4 Out-of-Market Ancillary Services

In addition to reserves, ISOs and RTOs require system resources to provide black-start service (compensated based on the contract agreement) and voltage and reactive power support (not compensated through the market or contract). Hydropower and PSH can provide these services.

All ISOs/RTOs (except ERCOT, which is not under FERC's jurisdiction [ERCOT 2022]) use the FERC Electric Tariff ("the Tariff") as guidance for compensating black-start units and voltage and reactive power. According to the Tariff, generation units and energy storage resources with black-start equipment are compensated based on the annual revenue requirement, and the fixed costs are calculated for existing generator investment by using 1% of the cost of new entry for hydropower and 2% for other resources (MISO 2023a).[33]

Compensation for voltage and reactive power support is established in the Tariff (MISO 2023a) and is handled through similar out-of-market mechanisms where the ISOs/RTOs oversee the buying and selling of these services. They could be the counterparty for purchasing reactive supply from generation or other sources and market sellers, as well as for selling reactive supply to transmission customers and market participants. Some regions, such as MISO, do not compensate generation resources if they provide reactive power support within the standard power factor range that is defined in MISO's Tariff document (MISO 2023a).

3.3 Compensation Mechanisms From Public Policies

RECs are mechanisms used in both vertically integrated and restructured energy markets. A REC is generated with each megawatt-hour of renewable energy and tracks renewable energy generation to facilitate compliance with mandatory RPSs. The RECs depend on the supply and demand for RECs and policy-set alternative compliance payments. Hydropower facilities aiming to decrease risk and maximize revenue often examine these mechanisms when considering potential projects. RECs from RPS programs are a common public-policy established mechanism to increase revenue adequacy to eligible technologies. Other public policy mechanisms can include carbon pricing, long-term contracting requirements, feed-in-tariffs, and PURPA qualifying facilities, among others.

3.3.1 Power Purchase Agreements

A PPA is a long-term contract between a power producer and an offtaker (a consumer that is typically a utility, government agency, or private company) that outlines the terms and conditions for the sale and purchase of electricity over an extended period, often spanning 10 to 25 years at a predetermined fixed price or price schedule. PPAs are common in energy project financing, such as for wind, solar, and hydroelectric power generation, because they provide investors a means to estimate stable returns from future cash flows and mitigate risk associated with potential fluctuating market prices.

For consumers, a PPA provides predictability in energy costs. They can budget with confidence, knowing that the price they will pay for electricity from the PPA is known in advance, which helps them manage their long-term financial planning. A PPA can be used for hedging to manage and mitigate risks associated with fluctuating energy prices, while also supporting sustainability and regulatory compliance goals. The effectiveness of a PPA as a hedging tool hinges on the negotiated terms, including the fixed price, contract duration, and flexibility clauses. Negotiating PPAs therefore requires a thorough financial analysis to align terms with the parties' goals and risk management strategies. The PPA should indicate which party manages and retains each of the products or revenue streams, such as which party receives RECs, carbon credits, etc. The prices of PPAs change with the terms, so a PPA that sells energy and RECs at a single dollar-per-megawatt-hour rate would see a higher price than a PPA that covers only energy. When a PPA includes RECs, it means that the buyer not only gets the physical electricity but also the associated environmental benefits. This can be attractive to buyers with sustainability goals or regulatory requirements to meet renewable energy targets.

A project that executes a PPA can be more attractive and less risky to investors, particularly commercial banks providing debt financing, when investors are comfortable with offtaker credit risk but unwilling to take on power price risk. Similarly, PPAs provide assurance to power producers, as they have a contractually committed offtaker at known prices. Ultimately, a PPA exchanges the commodity price risk a merchant project faces for a credit risk of the offtaker. Power purchase agreements (PPAs) for larger thermal power plants were once 20 years or longer, though the recent trend is for shorter PPAs due to greater market price volatility. Because a hydropower plant can operate for decades, a longer-term PPA is desirable from the perspective of the developer. A hydropower plant PPA can often range from 15 to 35 years. Puget Sound Energy in Washington state announced on March 24, 2020, that it signed a 15-year PPA with Energy Keepers for 40 MW of hydroelectricity from the Selis Ksanka Qlispe hydroelectric project in Montana (Water Power West 2020). Allegheny County in Pennsylvania entered into a 35-year PPA with Rye Development to purchase 7.4 MW of renewable electricity from a new low-impact run-of-river hydropower facility in 2021 (Office of County Executive Rich Fitzgerald 2021).

Volume uncertainty in power systems refers to the unpredictability and variation in the quantity of electrical energy that can be generated from various sources over a specific period of time. Renewable energy from variable resources such as wind, solar, run-of-river, or conduit projects have greater volume uncertainty. Powered dams with adequate storage typically have low volume risk. While PPAs for solar and wind projects typically contain performance requirements, the range of their acceptable performance may be wider, and the level of performance may be lower than hydropower. These differences may reduce the risk of not meeting performance targets for variable renewable facilities, but also reduce revenue certainty.

Corporate interest in sustainability and using renewable energy (such as part of environmental, social, and governance [ESG] programs) for their own power consumption has created a relatively newer class of market offtakers. Some new market entrants, such as Gravity Renewables, have had success in entering into agreements with universities (Gravity Renewables 2015).

3.3.2 Renewable Portfolio Standards and Renewable Energy Certificates

RPSs are state-level mandatory targets to sell a certain amount of electricity from renewable energy sources by a certain date. Because individual states establish their RPSs, program requirements vary vastly by state. Figure 14 shows RPSs by state and if they are mandatory (renewable portfolio standard) or voluntary (renewable portfolio goal).

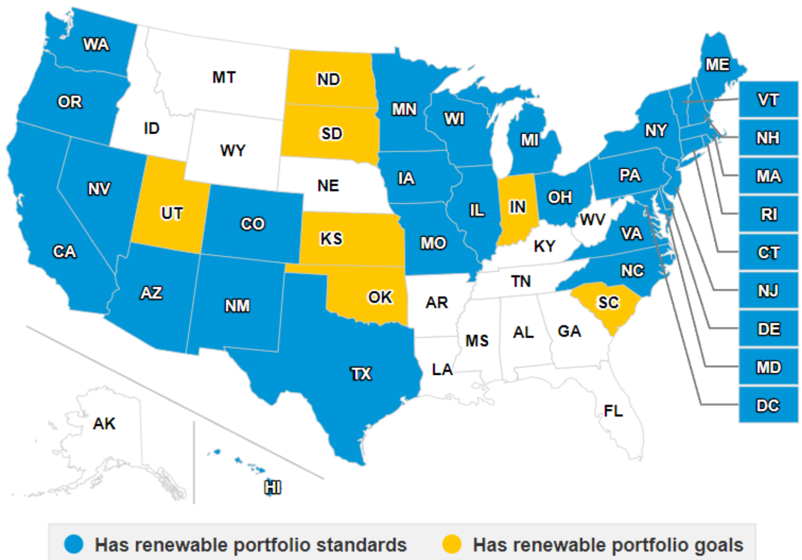

Figure 14. RPS map as of November 2022.

Source: EIA (2022b)

Mandatory RPS programs support the development of renewable energy resources, like hydropower, wind, and solar, by increasing requirements to build and sell renewable energy. States with ambitious RPS targets, such as Rhode Island (100% by 2033), could be more favorable locations for hydropower development compared to states with no or low RPS targets. Eighty-one percent (81%) of developers and 60% of investors surveyed responded that mandatory RPSs were likely or extremely likely to affect investment in hydropower and PSH.

More than half of states with an RPS requirement have placed restrictions on hydropower, from size to environmental considerations. For example, Arizona considers hydropower facilities built prior to 1997 as RPS-eligible technology only if their capacity has been increased due to improved technological or operational efficiencies. It also considers facilities that are used to firm or regulate the output of other eligible, intermittent renewable resources to be RPS-eligible. Arizona also includes new hydropower facilities installed after Jan. 1, 2006, that have a capacity of 10 MW or less and do not require a new dam, diversion structures, or a change in water flow that may adversely impact fish, wildlife, or water quality (Arizona Corporation Commission 2006).

Pennsylvania established its Alternative Energy Portfolio Standard (analogous to an RPS) with qualified sources of alternative energy credits (analogous to RECs). The program has different tiers of resources (based on technology) and requirements. Tier I credits include photovoltaic solar and "low-impact" hydropower[34] among others. Tier II credits include large hydropower (i.e., not low-impact hydropower, not necessarily based on capacity), PSH, and other resources like waste coal. The tiers effectively create submarkets for alternative energy credits with

[34] The Commonwealth of Pennsylvania defines low-impact hydropower as "consisting of any technology that produces electric power and that harnesses the hydroelectric potential of moving water impoundments, provided such incremental hydroelectric development: (1) does not adversely change existing impacts to aquatic systems; (2) meets the certification standards established by the Low Impact Hydropower Institute and American Rivers, Inc., or their successors; (3) provides an adequate water flow for protection of aquatic life and for safe and effective fish passage; (4) protects against erosion; and (5) protects cultural and historic resources" (PA Public Utility Commission 2022).

potentially different prices, with Tier I likely at a premium to discounted Tier II credits. Sources of alternative energy credits do not need to be physically within Pennsylvania. Of the Tier II alternative energy credits retired in 2022, 65% came from Pennsylvania and as much as 28% were Virginia-sourced (PA Public Utility Commission 2022).

Ohio established an RPS that qualifies hydropower based on technology, capacity, and online (commissioning) date. Traditional hydropower generally qualifies and must meet certain environmental conditions, and small hydropower (less than 6 MW aggregate capacity) qualifies while being exempt from some of those conditions. Run-of-river hydropower can qualify if placed into service on or after Jan. 1, 1980, is on the Ohio River, and has a capacity of at least 40 MW. PSH can qualify if the facility "will promote the better utilization of a renewable energy resource" (Ohio Laws 2023). Qualified hydropower must also be "within or bordering [Ohio] or within or bordering an adjoining state" (Ohio Laws 2023).

RPSs have been important for catalyzing renewable energy investment over the past several decades. Since 2000, nearly half of all growth in renewables capacity is associated with RPSs (EIA 2022b). However, some RPSs have restricted the ability for hydropower to participate. Pennsylvania and Ohio RPSs are good examples of incentives for small or low-impact hydropower (and PSH) by treating them differently than large-scale PSH.

A REC tracks renewable energy generation and facilitates mandatory RPS compliance and voluntary REC purchases (e.g., for corporate ESG initiatives). RECs establish an additional revenue stream for eligible projects, facilitating project finance. Renewable resources receive RECs for their generation, usually one REC per megawatt-hour. In some states, through the use of multipliers, the RECs generated can be higher than one REC per megawatt-hour to create a technology preference in their RPS (e.g., 1.5 RECs/MWh for solar).

RECs are used to meet mandatory RPS compliance, either by building projects, contracting for project offtake, or purchasing credits on the spot market. Several factors can affect the value of RECs: (1) the cost of qualified resources, (2) market price that reflects supply and demand for RECs, and (3) alternative compliance payments or the "floor price" set by policy, if applicable. Because REC prices depend on the supply of and demand for RECs, those states that have the most ambitious RPSs tend to have the highest demand for RECs and should be more favorable locations for new projects. Hydropower facilities aiming to capture REC revenue should consider these factors in estimating the potential contribution from RECs.

The voluntary REC market includes renewable energy procurement by retail electricity customers above a state's RPS mandates. The voluntary REC market includes six types of products: utility green pricing, utility renewable contracts, competitive suppliers, unbundled RECs, community choice aggregation, and PPAs (Sumner et al. 2023). In 2021, the market had about 8 million customers that bought 244 terawatt-hours of renewable energy.

To maximize the revenue potential of RECs, a hydropower facility should consider the possible REC markets for which it may qualify based on the facility's technology. Because REC prices depend on the supply of and demand for RECs, those states which have the most ambitious RPSs tend to have the highest demand for RECs and should be more favorable locations for new projects. Hydropower facilities looking to capture REC revenue should consider these factors in estimating the potential contribution from RECs.

4 Challenges Raising Required Investment Throughout Development Life Cycle

Each phase of hydropower or PSH project development includes unique risks, challenges, and capital requirements. This section introduces the project life cycle and discusses investment needs and risks at each stage. This section also highlights the six key challenges that impact the investment appetite for hydropower and PSH based on stakeholder interviews and surveys.

In general, as a project progresses through each development phase (i.e., early-stage and late-stage planning, construction, and operations), the risk profile of the project steadily decreases. A project's risk profile plays an important role in determining its ability to access capital and be successfully constructed and commissioned. Figure 15 summarizes a generalized development life cycle of a hydropower project (with aspects relevant for PSH development), including the major project milestones, risk profile perceived by investors, typical activities for developers, financing required, and financing available.

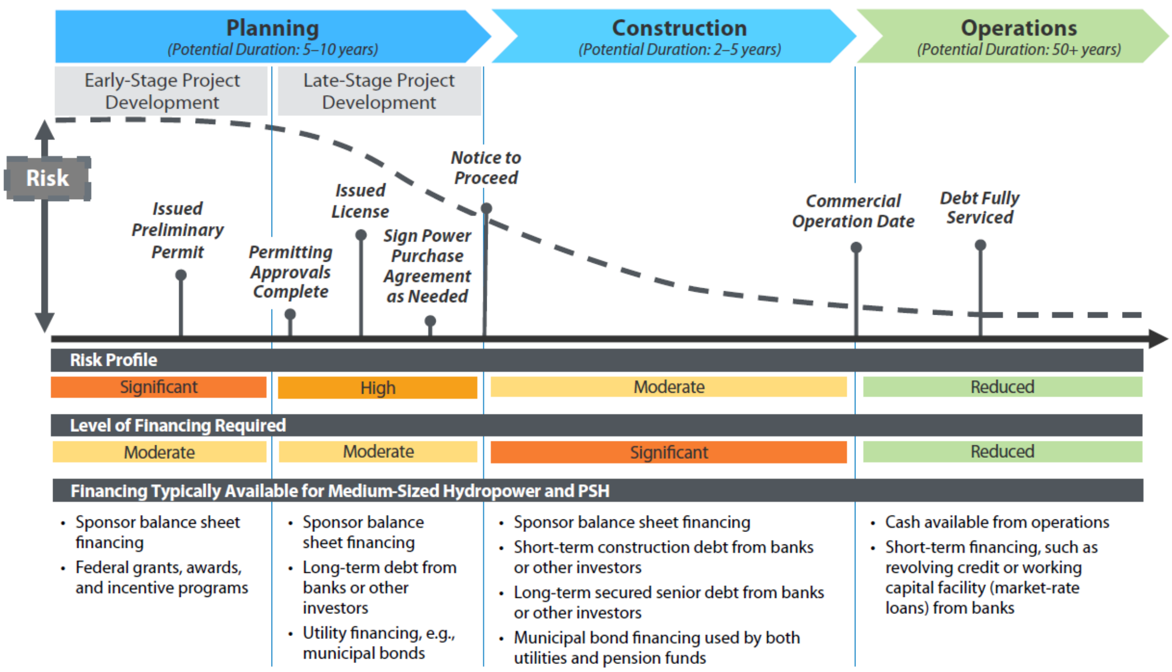

Figure 15. Hydropower project development stages and the interplay of risk and financing needed

In the investment survey, investors were asked about the stage of project development at which they plan to invest in the future; their responses are shown in Figure 16. Investors are most likely to invest in the later stages of development where risks are lower, i.e., once the permitting and licensing process is underway or complete. This response also underlines the challenge of accessing the necessary financing for early-stage planning, with only 8% of investors responding that they were likely to invest in this stage.

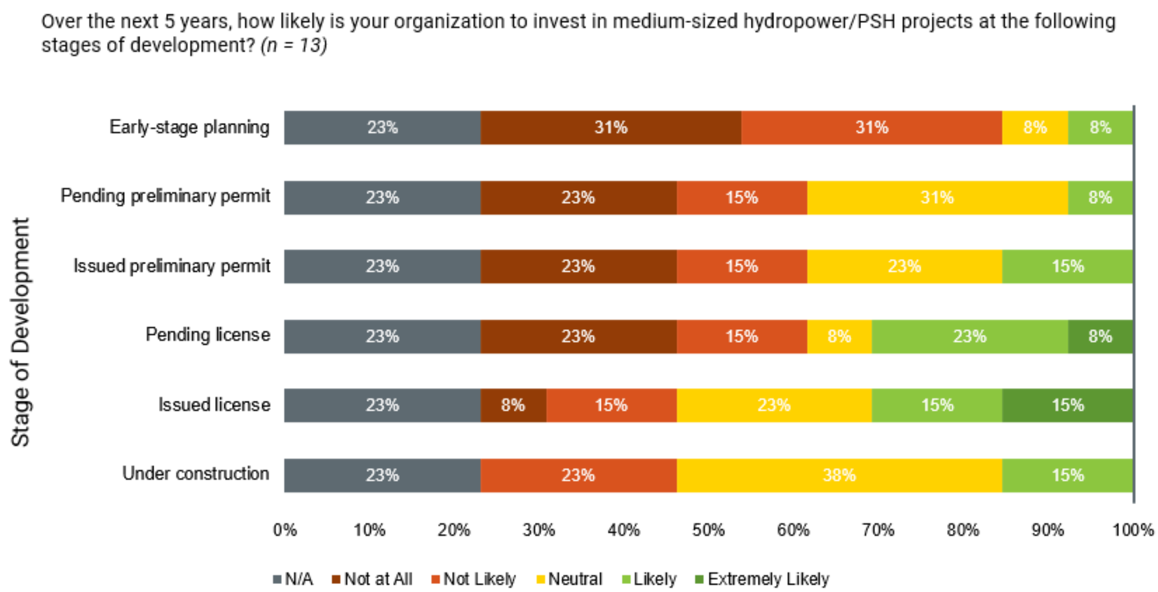

Figure 16. Investors' future investment plans by stage of development

Investors and developers also responded to a question focused on identifying the barriers most likely to influence either their investment or development of medium-sized hydropower and PSH. The investor and developer survey results are shown in Figure 17 and Figure 18, respectively. Investors surveyed noted the factors most likely to impede future investment included many of the challenges highlighted throughout this section, including inadequate market compensation for firm capacity, being approached too early in the development process, and revenue risks (i.e., no PPA). Developers surveyed noted the factors most likely to impede future development included long/extended licensing and permitting timelines, long payback periods, challenges in securing a PPA or insufficient PPA terms, and inability to generate a minimum return on investment.

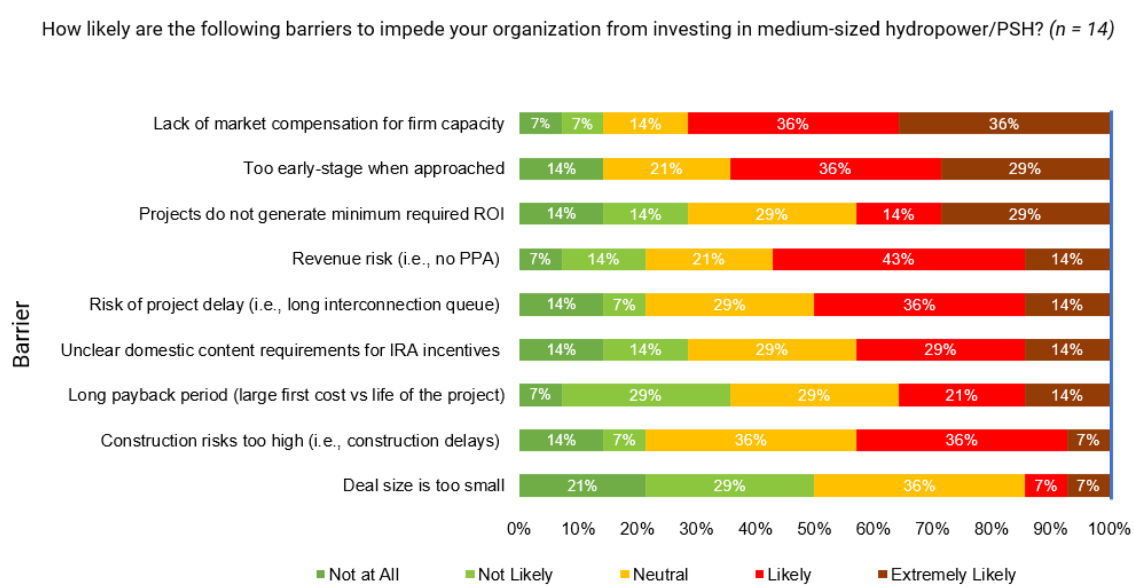

Figure 17. Barriers for investors

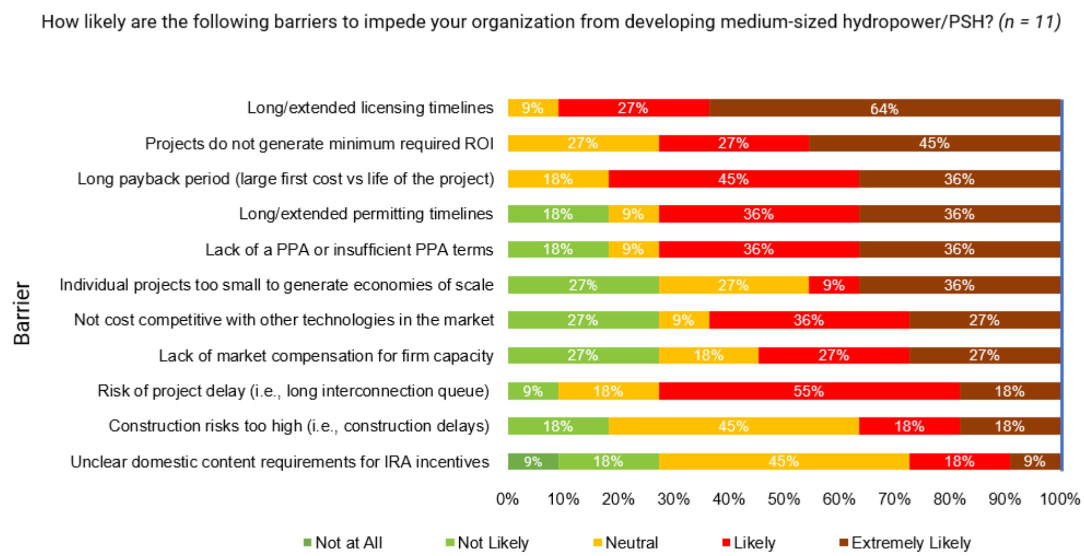

Figure 18. Barriers for developers

The responses from the surveys and interviews informed the prioritization of the six main investment challenges highlighted below. The sections that follow provide additional detail on the different development phases, as well as investor and developer perceptions of investment barriers along the life cycle.

4.1 Planning Phase

The planning phase has two stages: early-stage and late-stage project development.

4.1.1 Early-Stage Project Development

Early-stage project development is the phase that spans from site identification to the completion of pre-feasibility studies, feasibility studies, and preparation and submission of required permitting and licensing applications. Currently, due to various risks and barriers that disincentivize investment (discussed below), early-stage project development is primarily funded using some combination of developer or sponsor balance sheet financing, government grants, and (for public utility companies) municipal bonds.[35] Stakeholders interviewed shared that additional funding or financing during early project development, as well as more transparent and efficient permitting and licensing processes, could help raise additional investment and incentivize new development. Figure 19 summarizes the typical activities that take place during early project development.

Figure 19. Hydropower early-stage project development activities.

Adapted from Markkanen and Plummer Braeckman (2019); Guerrero (2021b)

35 Municipal bond would only be for municipally owned public utilities, not investor-owned public utilities.

When hydropower developers seek authorization to construct and operate a nonfederal hydropower project, they must file an application with FERC and/or with the owner of the facility such as with facilities owned by Reclamation or USACE. The owner is then responsible for analyzing the proposal and making recommendations on whether to authorize the proposal, and, if so, what conditions to include in the authorization (FERC 2017).

The sections that follow discuss the different components of early-stage project development, while highlighting two of the key challenges identified: long permitting and licensing timelines and lack of early-stage funding.

4.1.1.1 Key Investment Challenge 1: Licensing and Permitting

FERC issues three types of authorizations: preliminary permits, licenses, and exemptions. Developers also must secure permits from other agencies depending on location and land ownership, including USACE, Bureau of Land Management, Reclamation, U.S. Forest Service, U.S. Fish and Wildlife Service, NOAA Fisheries, various state agencies, and Indian Tribes (FERC 2017). This process can take up to a decade (Guerrero 2021a). There are a number of reasons why the licensing and permitting process is long for hydropower projects, including but not limited to the environmental complexity of projects and the need to comply with the Endangered Species Act and Clean Water Act, turnover at state and federal agencies, higher per-unit-of-energy licensing costs for small- to medium-sized projects as compared to larger projects, disagreement about necessary information in license applications, and participation from up to 11 federal and state agencies (Levine et al. 2021).

A hydropower license authorizes a developer to construct and operate a project (original license) or to continue to operate an existing project (relicense). An exemption allows small/low-impact hydroelectric projects having limited environmental impacts and meeting certain criteria to be exempt from the licensing process—typically conduit projects of less than 40 MW and small hydropower projects of less than 10 MW that will be built at an existing dam or add capacity to an existing project or use a natural water feature for head (FERC 2017). The average time to obtain an original license is 5 years (Levine et al. 2021). As shown in Figure 16, given the high costs of the licensing and permitting process, few investors are likely to invest prior to developers obtaining a pending or issued preliminary permit.

In addition to the challenges with long FERC licensing timelines, interviewed project developers noted that there is a lack of synchronization between USACE permitting processes and FERC licensing processes. Especially in USACE districts where there are few hydropower projects, regulatory timelines and processes can be uncertain. Because USACE owns the majority of NPDs, their uncertain regulatory timelines pose a large barrier to future hydropower fleet growth. As of July 2016, FERC and USACE signed a Memorandum of Understanding (MOU) to support increased synchronization and coordination (FERC 2016); however, according to publicly accessible records, limited action has been taken since the signing of the MOU. It may be beneficial to revisit the MOU and involve senior leadership from USACE and DOE to advise on the appropriate next steps. Per stakeholder feedback, additional coordination between FERC and the higher levels of leadership within USACE could facilitate increased adoption of the MOU. Of 11 developers surveyed as a part of this report, all of them noted that supporting more transparent and efficient licensing and permitting processes with FERC and other federal agencies is likely or extremely likely to accelerate investment in medium-sized hydropower and PSH.

Costs for licensing and permitting, including from FERC and state, municipal, and environmental authorities, along with other permits, can amount to up to 25%–30% of the total overall project cost (Guerrero 2021a) and can be a deterrent for investors providing financing (debt or equity) prior to projects securing a license. Stakeholders interviewed noted that extended timelines for relicensing can lead a project owner/sponsor to surrender their license and decommission the facility.

4.1.1.2 Key Investment Challenge 2: Access to Early-Stage Funding

Due to early-stage risks and long lead times between early-stage planning and when plant operations would generate cash flows, project developers find it difficult to secure much-needed investment (in particular, debt financing) to advance projects. Utilities, however, often have access to more financing mechanisms because commercial banks typically view investing in a utility (and their entire portfolio) as less risky than investing in an IPP for a single hydropower project.

Based on stakeholders surveyed (representing 14 investors), only 8% of investors shared that they would be likely to invest during the early-stage planning phase, while 62% shared they would "not likely" or "not at all" consider investing during this early phase. However, 31% of investors surveyed noted that once project developers have a pending license, they would be likely or extremely likely to invest. Lack of access to early-stage external investment (primarily debt financing) means that only well-capitalized project developers are likely to successfully move projects through the planning process to construction when financing is easier to raise. This factor limits new project development. Federal funding to support early-stage project development, including through grants and technical assistance, could support expanded development activity.

4.1.2 Late-Stage Project Development

In late-stage project development, the developer primarily focuses on finalizing the licensing process (i.e., obtaining an issued FERC license), interconnection studies, lease and easement considerations, and arranging an offtake agreement or PPA, when applicable. The sections that follow examine the different components of late-stage project development and highlight two of the key challenges identified: difficulties in securing PPAs and inadequate market compensation.

4.1.2.1 Key Investment Challenge 3: Securing Power Purchase Agreements

Most offtakers require all federal, state, and local permitting, as well as the FERC license, to be finalized prior to beginning a conversation on the terms of a PPA. While a PPA is not required in all cases, it does help mitigate risk for potential investors and is therefore an important element for investors.

Many investors require long-term PPAs (at least 10 years in duration) as a condition to mitigate the potential revenue risk if electricity prices were to drop prior to disbursement of capital. However, project developers find it difficult to secure PPAs with potential offtakers, particularly in the early stages of the project development timeline and for long-term tenures according to the stakeholder survey. For an offtaker, there is little motivation to sign a long-term PPA early because wholesale electricity prices can change significantly during the project development time frame. Instead, most utilities and electricity generators typically do not consider signing a PPA until the project has been issued a FERC license (if applicable) and is close to construction, according to interviewed stakeholders.

This paradox leaves project developers with the burden of financing early-stage project development to bring projects to the point where offtakers would agree to sign a PPA. In certain cases, this burden could be higher than the project developer is able or willing to take on. For example, ORNL analyzed FERC's dataset of projects obtaining licenses between 2007 and 2018, of which developers surrendered seven projects with more than 50% citing the inability to secure a PPA as the primary reason for the project's cancellation (Uría-Martínez, Johnson, and Shan 2020). Many developers further noted in the survey that challenges to negotiate and secure a PPA for hydropower projects can be due to low wholesale electricity prices, as well as competition from solar and wind (Uría-Martínez, Johnson, and Shan 2020). In a stakeholder interview, an engineering, procurement, and construction (EPC) company expressed concern that the lack of PPAs for most projects is preventing them from moving forward.

Typically, debt investors prefer to structure terms such that the project services debt in a tenure is shorter than the PPA as a means to reduce revenue risk. If the project developer secures a shorter-term PPA, such as a 5-year PPA, a debt investor may still be interested in the project but would likely require debt service over the shorter time frame. Meeting debt servicing obligations over such a short time frame could in this case be untenable for hydropower and PSH projects. More than 90% of investor respondents to the survey would prefer to use a long-term PPA (more than 10 years) to mitigate revenue risk, while 36% would be likely or extremely likely to use a short-term PPA (less than 10 years).

Developers and offtakers can structure PPA pricing in a variety of ways best suited to meet the requirements of the investor, power producer, and offtaker. In many cases, PPAs adopt a simple structure with a fixed price that escalates based on inflation or another escalation index. Given the utility's concern with committing to long-term fixed prices, PPAs in the hydropower market may benefit from more flexible terms. For example, there are PPA structures in the solar industry that incorporate a lower fixed price but allow power producers and offtakers to share the potential upside from higher wholesale prices than the fixed price (as well as share the potential downside if it drops below the fixed price) (Marsh et al. 2022). Flexible PPA terms such as this could incentivize offtakers to commit earlier on and for longer PPA tenures, which would benefit power producers as it would facilitate their access to investment dollars.

4.1.2.2 Key Investment Challenge 4: Market Compensation

As discussed in Section 3 of this report, market compensation for power produced and grid services provided by hydropower and PSH plants is a key factor in determining whether a project is bankable and can raise adequate financing to be constructed, operated, and maintained.

As dispatchable fossil fuel generation is retired, VRE generation is expected to make up a growing share of the generation fleet. Increased penetration of VREs can result in greater intra-daily fluctuation of wholesale power prices. As the share of VRE grows, the focus should be on adequate energy in addition to the peak demand because the available output of VRE can vary significantly throughout the day (PJM 2021). To combat this volatility in wholesale energy markets, hydropower developers may seek to diversify and expand potential revenue streams, for example by participating in capacity and ancillary service markets. However, hydropower investors may require more than the revenue obtained in these existing markets to recover hydropower LCOE. While promising in theory, more research is needed to understand whether expanded ancillary service markets that compensate for services like inertial frequency response, ramping, and commitment flexibility, could make hydropower projects more attractive.

Inertial frequency response can be helpful in limiting frequency excursions following grid disturbances, helping to keep the grid operating in times of stress. This service is not compensated today in any ISOs/RTOs.

The need for ramping and commitment flexibility has been recognized and paid for in CAISO and MISO. A similar approach in other ISOs/RTOs could help to procure an adequate level of ramping and commitment flexibility to maintain supply and demand balance throughout the day when VRE outputs rapidly change based on weather. As discussed in Section 3, where employed in each regional electricity market, these markets can increase revenue sources for a hydropower or PSH facility, support revenue stability, and reduce the risk profile of a project as compared to projects that only have access to wholesale energy markets.

4.1.2.3 Transmission Interconnection

Transmission interconnection agreements, frequently cited as causes of delays, are often incorporated into the PPA or signed as stand-alone contracts. Finalizing these agreements requires transmission system impact studies to ensure interconnecting the generation project does not harm system reliability. Due to the new rule FERC approved on July 28, 2023 (Order No. 2023),[36] the delay risk due to long transmission interconnection queues may be decreased, with measures aiming to cut the current 5-year wait time (FERC 2023c). This change is relatively recent, so its impacts remain unclear.

4.1.3 Risks During Project Planning Phase

Various risks during planning can prevent investor participation in a project, particularly because many of these risks can create significant timeline delays. Table 3 outlines key risks that could impact project development and potential investment during this phase, as well as some illustrative mitigation options for each risk based on input from the survey, along with industry analysis.

[36] FERC Order No. 2023 includes changes to the interconnection process so that related requests are processed once interconnection customers reach certain development milestones, rather than the previous first-come, first-served approach (des Rosiers, Salalayko, and Green 2023).

Table 3. Potential Risks During Project Planning Phase

Risk Type	Possible Impact on Investment	Illustrative Mitigation Option(s)
Permitting and Licensing Risk: Delays and long timelines	• Extended timelines (of 5 years and above) make it difficult for project developers to access traditional debt financing during the early development stages.	• Improve transparency and efficiency of FERC licensing process for capacity additions, NPDs, and small/low-impact projects beyond 10 MW. • Issue guidance for developing projects, such as FERC's guidance for developing closed-loop PSH (FERC 2019). • Re-focus efforts on the 2016 MOU between USACE and FERC to synchronize licensing processes for NPDs. • Pursue grant funding to support costs for preparation of applications and initial development activities. • Synchronize review processes under Clean Water Act and USACE processes between states.
Engineering and Design Risk: Uncertainty of underground construction, impacting feasibility of original design	• Despite early-stage design and planning, costs for construction can increase if, during initial construction phases, the developer discovers underground or soil considerations, making original design difficult to implement.	• Conduct comprehensive early engineering studies (front-end engineering design), which are important to understand risks to construction design based on soil quality, subterranean issues, etc.
NPD Design Risk: Higher costs especially when powering NPDs	• As NPD sites were originally used for purposes other than hydropower, resource use requirements could limit design configurations, making it more risky or more costly (DeNeale et al. 2022).	• Utilize existing NPD studies to identify and prioritize most suitable sites for optimal facility design and configuration and avoid sunk design costs.
Technology Risk: Potential for today's technologies such as PSH to become obsolete with future technologies	• Investors and developers may be interested in PSH but also believe that a cheaper and more effective battery storage technology is on the short- to medium-term horizon, which would make signing a long-term PPA seem like a poor decision.	• Continue DOE grant programs to develop innovative technologies and support demonstration projects that could be used to make PSH cost competitive on a long-term basis as battery technology improves and costs decline. • Consider hybrid projects with PSH to increase the total opportunity value.
Project Developer Risk: Limited track record	• Investors prefer developers and EPCs with a strong track record, making it more difficult for new entrants to obtain financing.	• Encourage joint ventures with experienced developers. • Use technical advisors.

Risk Type	Possible Impact on Investment	Illustrative Mitigation Option(s)
Community Buy-In Risk: Lack of community support	• Lack of buy-in from community can delay or stop a project, increasing risk and cost for investors.	• Incorporate community engagement early and often to identify potential community benefits from projects. • Create multi-stakeholder task force to engage local community. • Support community-based programs and workforce development.
Environmental Regulatory Risk: Changing or unclear environmental regulatory requirements	• Environmental regulations and requirements related to water, sedimentation, erosion, wildlife, etc. are often complicated (i.e., fish passages) and vary by state, which can cause delays that significantly increase costs.	• Identify federal, state, and site-specific environmental requirements early. • Review previous relicensing cases to identify opportunities to make relicensing more transparent and efficient and reduce license surrender risk.
Revenue Risk: Inability to secure a PPA[37]	• Lack of a PPA increases project revenue risk, resulting in limited or no investor interest.	• Negotiate PPA terms that are long enough for investor interest but flexible enough for offtakers.
Interconnection Risk: Delay due to long interconnection queue	• Long interconnection queues and the need to meet requirements of utilities, interconnection point owner, and the ISO increase project cost and uncertainty, making it more difficult to secure finance for construction. • High cost of interconnection.	• FERC's new rule (Order No. 2023) was issued in an attempt to reduce interconnection delays.

4.1.4 Financing Options for the Planning Phase

Due to the risks listed in Table 3 and discussed earlier, the lack of access to early-stage financing and funding is a primary barrier limiting potential hydropower development. Federal agency financing support (such as from the DOE Loan Programs Office (LPO) or USACE Corps Water Infrastructure Financing Program (CWIFP)) in the form of funding for design studies, feasibility, or licensing and permitting would help fill a critical financing gap and support later-stage participation from institutional investors, PE and VC funds, and commercial banks. Typical project financing[38] as seen in international markets for hydropower or for other renewable energy sources, like solar or wind, has not been applied to U.S. medium-sized hydropower or PSH in recent years, particularly due to small deal sizes, long lead times, high construction costs, and better return on investment from other project types like solar and wind. Solar experiences faster

[37] Results from the stakeholder survey indicated that the inability to secure a PPA and/or insufficient tariffs was one of the barriers most likely to impede project development.

[38] Typical project financing refers to off-balance-sheet financing (or limited or non-recourse financing), in which a special purpose vehicle is created as the project company. The project sponsor and investors invest in the special-purpose vehicle and are paid back solely from the project's future cash flows.

development timelines, easier siting, and product replicability. Hydropower, in comparison, has been site-specific, although new market entrants (e.g., Emrgy—see case study in Section 2.2.5) are working to deploy more scalable technologies, which lessen this linkage and have the potential to decrease development timelines. During development phases closer to construction, projects often have access to debt financing and can more easily secure investment, particularly if developers can secure PPAs.

4.2 Construction Phase

The construction phase spans final equipment procurement, site preparation, construction, equipment installation, interconnection, and commissioning. Based on stakeholder interviews, financiers will often request a finalized offtake agreement that in turn requires the developer to have begun construction and have a set a commercial operation date. Once all permits or contracts are in place from FERC and other relevant agencies, the project developer may issue a notice to proceed to the EPC contractors and suppliers to begin construction activities. The construction phase is complete when the plant enters commercial operations. The section that follows highlights a key challenge of how hydropower has high construction costs, which are amplified with long timelines before investors receive a return on their investment, which can result in reduced interest from investors compared to other shorter-term and cheaper investment options.

4.2.1 Key Investment Challenge 5: High Development and Construction Costs for Energy Production and Unclear Costs for Providing Firm Capacity

In theory, markets harness the power of competition to allocate capital efficiently. Energy sector investors are often technology-agnostic and consider hydropower in the context of a multi-asset allocation strategy in search of the best return. In today's world, most energy sector investments are considered on the basis of cost per unit of energy; however, the cost per unit of firm capacity is emerging as an important metric because firm capacity, a capability key to low-cost VRE integration, is not easily provided by most renewable technologies. Construction costs related to providing these two services are discussed below.

The EIA provides energy-production-related construction costs for common forms of renewable generation technologies (EIA 2023a). In 2022, EIA estimated 2023 capital costs for energy delivery from conventional hydropower and other renewable energy sources including geothermal, solar, and wind. While not the most expensive renewable option, the capital costs of conventional hydropower are more than twice that of solar and wind installations of the same size, as shown in Table 4.[39,40]

[39] Notably, "because geothermal and hydropower costs and performance characteristics are specific for each site, [this analysis] represents the cost of the least expensive plant that could be built in the Northwest region for hydro and Great Basin region for geothermal, where most of the proposed sites are located" (EIA 2023a).
[40] Life cycle costs and LCOE are included in the Operations Phase of this chapter in Section 4.3.2.

Table 4. Estimated 2022 Overnight Capital Costs for New Electricity-Generating Plants

Data source: EIA (2022a)

Renewable Energy Source	Estimated Capital Costs (2022 $/kW)
Solar photovoltaic with axis tracking	1,448
Wind	2,098
Solar photovoltaic with storage	1,808
Geothermal	3,403
Conventional hydroelectric power	3,421
Wood and other biomass	4,998
Offshore wind	6,672

Complicating the situation is that capital costs vary considerably by hydropower project type. Capacity-weighted mean averages for conduit, NPD, and new stream-reach development projects ranged from $3,955, $6,096, and $6,612 per kilowatt, respectively, based on a sample of 51 projects starting operations since 2005 ranging in size from 1.5 kW (new stream-reach development) to 105 MW (NPD) (Uría-Martínez and Johnson 2023).

What is not shown in Table 4 is how hydropower compares with other technologies in terms of its cost to provide firm capacity and low-carbon operating reserves. Historically, these services have not been of concern because they have been provided by fossil-fuel-fired generation (i.e., firm capacity, in many ways, was just a given). Unfortunately, VRE is not a good source of these services, and as fossil-fuel-fired generation is retired, other sources will be needed. Firm capacity is expected to become increasingly scarce and grow in value as fossil generation is retired from the grid (Gagnon et al. 2023).

The reason this is important to hydropower is that although the research in this area has been limited, the work to date shows that hydropower appears well positioned to be a low-cost provider for these services because it is one of the few forms of renewable energy able to provide these services (unlike many forms of renewable energy, hydropower is dispatchable). If the early research proves accurate, hydropower's ability as a cost-effective source of low-carbon firm capacity and operating reserves could be a key investment differentiator for the technology.

4.2.2 Risks During Construction Phase

Table 5 outlines key risks for consideration during the construction stage, their potential impact on investment, and some illustrative mitigation options for each risk based on input from the survey, along with desk research and analysis.

Table 5. Potential Risks During Construction

Construction Risk	Possible Impact on Investment	Illustrative Mitigation Option(s)
Supply Chain Regulatory and Procurement Risk: Uncertainty around domestic content regulations	• Lack of clarity on domestic content requirements in the Inflation Reduction Act tax credits impacts ability of developers to identify procurement constraints, estimate project costs and applicable incentives. • Increased risk due to lack of supply chain redundancy (i.e., supplier risk) can impact investor appetite.	• Request that federal agencies (such as the Internal Revenue Service) can provide greater clarity on domestic content regulatory requirements. • Develop project supply chain strategy that includes supplier identification and verification or develop exemption pathway if the supply chain does not exist or has long wait times. • Consider bulk purchasing of components and spare parts to reduce costs. • Prequalify vendors that meet domestic content requirements.
Construction Risk: Schedule and cost overruns or quality issues during construction	• Schedule delays, cost overruns, and quality issues cause delays and impact timing of project revenues. • Weather and unforeseen climate issues cause delays and increase costs.	• Include surety/performance bonds or construction insurance in EPC contracts to manage construction risk. • Select EPC contractors and suppliers through a competitive process that evaluates experience/capability and reliability.

4.2.3 Financing Options in the Construction Phase

By the construction stage, the risk profiles of projects are typically such that a developer can raise debt or equity financing, particularly if the project implementation team includes EPC contractors and suppliers with a demonstrated track record for managing construction at cost and according to schedule. Public utilities can finance the construction of hydropower and other renewable energy projects through their capital budgeting process with equity and debt,[41] including bonds, though many now procure power competitively from non-utility generators in the market. Bonds can provide stable investment opportunities for a variety of fixed-income investors such as banks or pension funds, whose investment criteria align with the long-term value of hydropower projects. In certain cases, experienced IPPs utilize non-recourse or limited-recourse bank debt (loans secured by collateral) and equity to fund construction.

4.3 Operations Phase

The end of the construction phase is usually marked by the commercial operation date, which is the date when the facility has passed the commissioning tests and begins to generate power to earn revenue. The commercial operation date typically takes place after an independent engineer certifies that the facility has been built to specifications and once the interconnection utility and/or ISO/RTO certifies that the facility is ready to deliver power.

[41] Public utilities typically must have all projects meet least-cost standards and pass regulatory scrutiny as part of their capital budgeting process.

4.3.1 Operating Costs

Capital cost requirements during operations are typically limited to major repairs, maintenance, and retrofits or upgrades of equipment. These capital costs are often funded through maintenance reserve accounts and sinking funds for major maintenance. Operations and maintenance expenses during this stage are funded through cash from operations and are often managed through a service contract with the operations and maintenance contractor or plant manager.

Per the EIA 2023 Annual Energy Outlook (EIA 2023a), the average variable and fixed operations and maintenance costs for conventional hydropower facilities are $1.57/MWh and $47.06/MWh of energy provided, respectively. By comparison, the EIA reports the average variable and fixed operations and maintenance costs for solar photovoltaics with tracking as much lower, at $0/MWh and $17.16/MWh, respectively. Per the 2023 *U.S. Hydropower Market Report* (Uría-Martínez and Johnson 2023), the age of the facility had a strong correlation to increased operations and maintenance costs, which is an important consideration given the aging fleet of hydropower assets.

In terms of the cost to provide firm capacity, only limited information is available that compares hydropower to other technologies, which is a significant gap in current valuation methods. As discussed in Section 3, firm capacity is key to low-cost integration of VRE. It is a capability in which hydropower appears to excel, and revenue streams for providing this service are expected to supply a substantial portion of hydropower revenues going forward (Stark and Brinkman 2023). Although a low-carbon grid is an expected scenario (e.g., much of the country has RPS provisions in place), the need for low-carbon, firm capacity is seldom considered in investment evaluations, which likely undervalues hydropower.

4.3.2 Life Cycle Costs

Unlike capital cost estimates discussed in Section 4.2, LCOE analyses can evaluate the lifetime costs of generating power from various sources. In 2022, EIA estimated a $52.53/MWh LCOE for solar, a $40.23/MWh LCOE for land-based wind, and a $64.27/MWh LCOE for hydropower (EIA 2022a). EIA used average capacity factors to calculate the renewable resources, and EIA notes that capacity factors can differ by region and LCOE could differ outside of the estimate based on project specifics. Stakeholders recommended it would be helpful to have an industry-published LCOE for hydropower that demonstrates its long-term value.

Similar to the concerns stated in the operating costs section, limited research has been conducted that compares the life cycle costs of various renewable technologies in terms of providing firm capacity. This is a gap in current valuation methods that likely undervalues hydropower.

4.3.3 Relicensing

Relicensing is a challenge facing project developers. Surveyed and interviewed stakeholders identified that the burden of relicensing, particularly for projects seeking relicensing with increased capacity, can be so high as to dissuade project developers from pursuing them. The average time to obtain a relicense is 7.6 years (Levine et al. 2021). A few interviewed project developers shared that they have a concern with relicensing because of the high regulatory burden that makes small impoundments not economically viable. However, they also shared that it is similarly expensive to surrender a license.

4.3.4 Risks During Operations Phase

Once the project is in operations, the risk profile shifts toward risks that could impact the continued operations of a plant (i.e., extreme weather events, droughts) and market and price risks (i.e., the uncertainty in future market design, price volatility, or low wholesale prices for a merchant plant) rather than the early-stage development risks. Table 6 identifies typical potential risks during operations, their potential impact on investment, and some illustrative mitigation options for each risk based on input from the survey, along with desk research and analysis.

Table 6. Potential Risks During Operations

Operations Risks	Possible Impact on Investment	Illustrative Mitigation Option(s)
Weather Event Risk: Flooding can damage plant/threaten future revenues	• Weather events, such as significant flooding and evaluations of probable maximum flood ratings, cause damage to facilities and lead to temporary shutdowns, impacting cash flows.	• Proper engineering design and flood insurance can mitigate potential impact of floods.
Hydrological Risk: Variable hydrology due to seasonal and annual fluctuations in rainfall can impact generation potential	• Droughts over multiyear periods can lead to partial capacity operations, impacting revenues over an extended period; may become larger risk with climate change.	• Reservoir management to store water during wet seasons and release it during dry seasons.
Climate Change Risk: Increased variability in hydrology due to seasonal and annual fluctuations in rainfall can impact generation potential	• As discussed in hydrological risk, climate change can result in certain areas receiving reduced rainfall or increased instances of drought, which would impact revenues and the operations of a hydropower plant (particularly a run-of-river hydropower plant).	• Reservoir management to store water during wet seasons and release it during dry seasons.
Unexpected Major Maintenance Risk: Unforeseen major maintenance required	• Plant may need to finance repair or maintenance costs and must pause operations, impacting revenue generation.	• Include a major maintenance reserve.
Market and Price Risk: High volatility in market spot prices	• For projects with a short-term or no PPA, decline in spot prices may make it difficult to meet debt obligations and cover operations. • For projects without a PPA dependent on market prices, fluctuating market prices make it difficult to forecast cash flows, causing challenges in securing financing.	• Pursue as long-term PPA arrangements as possible. • Maintain debt service reserve account. • If available, pursue other contracting mechanism to reduce revenue risk such as contract for difference or other revenue subsidy.
Power Purchaser Default Risk: PPA counterparty fails to fulfill obligations	• Default on a PPA contract could negatively impact revenues and credit profile of the project.	• Develop clear default obligations in PPA contract. • Use reserve accounts to reduce cash shortfall risk in this scenario.

4.3.5 Financing Options During Operations Phase

While a plant is in operations, the owner will typically have financial obligations to service debt and provide a return on equity. Until the project reaches steady state, the project owner will likely require access to short-term financing to satisfy their obligations, which could take the form of a revolving credit (variable line of credit providing loans as needed for operations) or working capital (a loan that covers short-term operational needs). Once the project is in steady state, the owner may consider refinancing the project debt for more favorable terms.

For older assets in need of significant upgrades, relicensing, or refurbishment, external financing may be necessary. For the purposes of this report, these projects are considered new projects and would progress through all the phases of development with all the above-mentioned financing characteristics and risks.

4.4 Additional Challenge Impacting Investment

While many of the key challenges that impact investment appetite for hydropower and PSH are related to specific phases of the project development life cycle, stakeholders identified another key investment challenge: investment industry awareness.

4.4.1 Key Investment Challenge 6: Industry Awareness

During stakeholder interviews, investors (particularly commercial banks) shared that they have rarely been approached by project developers for project opportunities in medium-sized hydropower or PSH. As a result, some interviewed commercial banks had limited awareness of medium-sized hydropower and PSH opportunities, including development of NPDs. Most investors do not have a mission to develop hydropower and, as a result, will not invest in hydropower unless it provides a financial return and strong economic business case. Communicating the industry-specific benefits (e.g., grid resiliency, electricity sector decarbonization) and project-specific benefits (e.g., alternative revenue streams from mandatory REC, capacity, and ancillary service markets) of hydropower and PSH to the investor community and to utilities, ISOs, and RTOs would support improved industry awareness and an improved understanding of the drivers of future potential investments in developing the hydropower and PSH fleet.

4.5 Summary of Challenges

When evaluating investment options, hydropower's high capital and operations and maintenance costs, incomplete market valuation (e.g., firm capacity revenues are expected to rise sharply yet are seldom considered in market valuation), and long regulatory and construction timelines makes it considerably less competitive than other renewables that offer higher, faster returns such as solar. Many challenges occur at various stages of the project development life cycle (Figure 20). During early-stage development, challenges for hydropower and PSH include (1) long project development timelines, particularly licensing and permitting, and (2) lack of access to early-stage funding. During late-stage project development, challenges for hydropower include (3) challenges in securing early-stage PPAs and (4) uncertain market compensation. During the construction phase, challenges for hydropower include (5) high development costs. Across the life cycle, (6) limited industry awareness is a general investment challenge for hydropower and PSH that can deter private investment. When comparing investment options, these barriers create a suboptimal business case for hydropower and PSH investment.

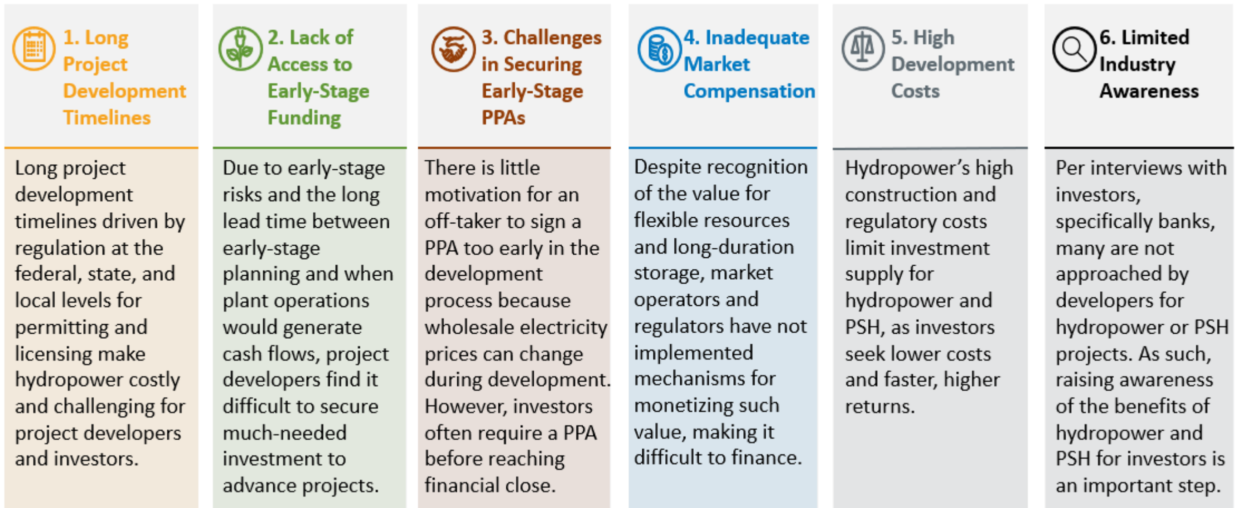

Figure 20. Summary of key investment challenges

5 Investment Landscape

This section of the report examines recent transactions in the medium-sized hydropower and PSH market and the profile of investors that have participated in recent transactions. It also details some of the specific motivations and perspectives that six investor groups have about investing in hydropower based on feedback from market interviews and surveys. Based on an assessment of the investor landscape, investors were categorized into six investor groups either currently involved or with the potential to be involved in hydropower and PSH in the United States, as shown in Figure 21. Each investor group discussed below has specific motivations driving their decisions to provide debt or equity financing. Understanding these driving motivations can help remove barriers currently impeding investor interest.

WHO	FINANCIAL FRAMEWORK	BACKGROUND / INTEREST IN HYDROPOWER
IPPs / PRIVATE PROJECT DEVELOPERS	Balance sheet and project financing based on portfolio of projects operating and in development.	**Developing and owning projects** based on geography, revenue potential, complexity and probability to get permits, regulatory framework, potential tax benefits, and project size. **Can justify earlier stage investment.**
INSTITUTIONAL INVESTORS	Long-term, low-risk equity and debt from pension funds, insurance companies, and other institutions.	Achieving a **target return** based on long-term liabilities and actuarial obligations. Pension funds and insurance companies are **patient capital** providers, but risk requirements usually **preclude early-stage funding**.
PRIVATE EQUITY AND VENTURE CAPITAL FUNDS	Medium-term equity from risk-tolerant qualified investors; high returns for PE and very high for VC.	Achieving a **target return** based on funds raised from their investors. Relatively **higher risk tolerance allows earlier-stage investment** for innovative, early-stage technology suppliers, and with limited early-stage project co-development alongside IPPs.
PUBLIC AND PRIVATE UTILITIES & CCAs	Regulated return on invested capital through rates paid into their system, plus balance sheet equity, debt, tax credits.	Pressure from regulators increasingly **focuses utilities on reliable power delivery, cost minimization, and power purchase by bid only**. Under competitive bidding programs, hydropower usually fares poorly against wind and solar. **CCAs can be enthusiastic buyers** of power from local hydropower and sometimes fund early-stage development.
COMMERCIAL BANKS	Risk-averse corporate or project loans for portfolios of projects or large single projects.	Banks that formerly were active in the small and medium-sized hydropower markets have been acquired and/or have gravitated toward larger projects. **Green investing** frameworks and upcoming **SEC accounting disclosure requirements** may motivate more investment in clean energy but not likely to drive banks into small projects or early stage.
TAX EQUITY INVESTORS	Highly-structured partnership minority equity in exchange for allocation of tax benefits.	Large corporations or banks with predictable tax liabilities. Prefer to come into a project **upon commercial operations** subject to a partnership agreement. Typically, **will not take development risk** or meaningful operating risk.

Figure 21. Potential investors and their interest in medium-sized hydropower

5.1 Summary of Recent Trends in Hydropower Transactions

As described in Section 1.2, the authors analyzed transaction data from the ORNL HydroSource database, Infralogic, S&P Capital IQ, FERC, and industry-specific websites in the development of this report. The data presented in this report provide an illustrative view of recent transactions to understand industry trends, which are based on publicly available information. Researched transactions from the last 10 years fall into three categories:

1. **Change in ownership (acquiring existing facilities):** Constitute the full or majority transfer of ownership (equity) of an existing hydropower facility or facilities from one entity to another. These transactions often involve a seller that is a private developer or IPP that originally developed and financed construction of the asset. Buyers can include developers/IPPs, PE/VC firms, and institutional investors, among others.

2. **Infrastructure investments:** Finance refurbishment or upgrades, powering NPDs, and greenfield hydropower projects. These are funded primarily by utilities and IPPs. It is

important to note that the illustrative transactions, such as those presented in Appendix A, show only where outside investment-facilitated development and does not portray development projects where IPPs or project developers self-financed using on-balance-sheet financing.

3. **Corporate investments:** Provide equity or debt financing to hydropower technology companies, project development companies, and/or hydropower equipment manufacturers/suppliers to fund a variety of activities.

Table 7 summarizes 43 identified, illustrative medium-sized hydropower and PSH transactions over the past 10 years.

Table 7. Number of Medium-Sized Hydropower and PSH Transactions (2013–2023) Across Investor and Investment Types

Investor Type	# of Ownership Changes	# of Infrastructure Investments	# of Corporate Investments	Total
Private Project Developers/IPPs	14	1	1	16
PE/VC Firms	5	2	9	16
Utilities	4	7	0	11
Total	**23**	**10**	**10**	**43**

The reviewed transactions can provide insight and understanding into the current market. A few key findings are briefly described below with more detailed descriptions in Section 5.2.

- **IPPs** have been active in acquiring existing facilities or portfolios to add to their current fleet of hydropower and PSH assets. Existing facilities can carry lower operating and investment risks, which can make them attractive options to grow an operating fleet instead of taking on early-stage development and construction risks in greenfield project developments.
- **PE/VC firms** have been active corporate investors in many innovative technology companies. Equity or debt investments in a company instead of a project can help minimize project-specific investment risks.
- **Utilities** have been active in acquiring facilities and financing various projects. Many utilities have access to early-stage funding and financing, particularly with corporate financing and municipal or revenue bond financing. Reliable access to financing can support early-stage development of infrastructure like hydropower.

5.2 Investor Profiles and Their Respective Recent Transactions

In addition to outlining investment motivations, this section reviews recent investor activity in the medium-sized hydropower and PSH market, provides explanations of the typical financing instruments used and takeaways from stakeholder engagement and industry research. This section highlights what developers may need to help raise equity or debt by each investor profile group.

5.2.1 Independent Power Producers and Private Project Developers

IPPs and private project developers are the principal drivers of the expansion of new project development, retrofits, upgrades, and add-on projects at NPDs and conduits. Many IPPs and private developers are small, regionally focused operations with a few projects in a specific geography that sell power to local utility companies. These smaller players have greater challenges financing projects since they often lack (1) large enough balance sheets to lend against and (2) an operating portfolio to provide risk diversification like utilities or large IPPs. Alternatively, larger IPPs, like Eagle Creek and Brookfield Renewables often function as both project developers/IPPs and owner/operators of existing assets, some of which they purchase from developers or other owner/operators before or after commissioning. Larger IPPs are often part of large holding companies or investment firms and tend to have greater access to internal and external financing.

Once a project is operating, IPPs often function as non-utility generators, also known as qualifying facilities,[42] and are permitted to own and operate generating plants and produce power for resale. Often, IPPs sell power to local utility companies under a PPA or at the utility's avoided cost.[43] Based on interviews with IPPs, private project developers often finance their own projects up to construction because commercial banks and other investors are not interested in or willing to take on early-stage development risk. While this can restrict a developer's ability to develop other projects or limit the size of potential projects, various project developers/IPPs noted in interviews that they finance their own projects for two primary reasons: (1) they maintain control of most early-stage project development risks and typically have experience managing these risks from other projects; and (2) they seek to maintain a large equity position in the project as it advances and are therefore positioned to benefit from higher long-term equity returns than a debt provider (higher risk is compensated with higher potential reward). Project developers' main motivation is typically to develop bankable projects that can sell energy to the grid, allowing them to recoup their initial investments, earn a return, and develop more projects. Project developers are frequently hydropower or renewable energy specialists that build projects aligned with their experience.

Of the IPPs/private project developers surveyed, the majority plan to develop medium-sized hydropower and PSH over the next 5 years, while a smaller number answered "no" or "maybe."[44] One project developer responding "maybe" shared that their interest depended on market rates, including real-time energy generation and PSH rates. Additionally, a project developer that answered "no" explained that they do not plan to develop hydropower because of the prohibitive regulatory environment, environmental stakeholder resistance, and low cost of gas.

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[42] Under PURPA, certain types of power generation projects can get "qualifying facilities" status, which requires utilities to buy their power, so some level of revenue may be assured.

[43] Avoided cost is the cost of power that a utility would avoid as a result of buying power from a qualifying facility. The price set for avoided costs is usually subject to highly contested debate and regulation.

[44] This survey is illustrative rather than exhaustive due to its limited sample size (11 IPP and private project developers responded).

Surveyed IPPs and private project developers who plan to develop hydropower in the next 5 years expressed a strong interest in powering NPD projects and conduit projects (with 63% answering favorably or extremely favorably for both categories), followed by capacity addition and hybrid projects (with 54% answering favorably or extremely favorably for both categories).

Table A-1 in Appendix A provides an overview of 17 recent medium-sized hydropower and PSH transactions (2013–2023) carried out by project developers and IPPs. Key takeaways are presented below.

- **Transaction Types:** Most of the private project developer and IPP transactions were acquisitions (15 of 17), with one infrastructure investment[45] and one corporate investment. The substantial portion of acquisitions suggests that much of IPP and private developer portfolio growth also comes from purchasing existing assets or seeking external investment for infrastructure development. Multiple sellers sold facilities that they deemed too expensive to maintain, which other developers then acquired and refurbished. For instance, Eagle Creek purchased the Reusens facility from AEP in 2017 after shutting down operations because of the need for costly repairs, then refurbished four of the five generator units to bring 10 MW onto the grid (Eagle Creek Renewable Energy 2023c).
- **Investor Diversity:** While Eagle Creek carried out 4 of the 17 transactions, no other company performed more than two transactions, indicating market diversity.
- **Trends Over Time:** More than half of the transactions occurred in the last 4 years (2020–2023), which may suggest more recent momentum for hydropower market activity and presents an optimistic picture for future project developer/IPP market involvement in the coming years.

5.2.2 Institutional Investors

Institutional investors include a variety of organizations that invest capital on behalf of clients or members. These firms can include private debt funds, pension funds, insurance companies, and the investment management arms of large banks. For the purposes of this report's investment landscape assessment, commercial banks are included in a separate category, as are PE and VC firms. Institutional investors can provide a variety of financial instruments to hydropower projects and project development companies, including but not limited to equity investments in portfolios of stocks traded on exchanges, non-recourse debt, construction loans, mezzanine, convertible debt, and more.

[45] Transaction data do not reflect a company's infrastructure investments in its own projects. Interviews and surveys with developers suggest that project developers/IPPs are the primary drivers of financing (through on-balance-sheet financing) of their own infrastructure developments.

These firms are well-capitalized and can invest in developing and developed (operating) project portfolios that align with their investment focus (including preferred geography, market, project sponsor capabilities, etc.). Generally, institutional investors prefer to invest in experienced and well-established project developers. The relatively long investment time horizon and cash flow stability of operating hydropower assets (typical for large infrastructure projects) can often align well with a fund's investment timeline. Notably, some institutional investors like pension funds and insurance companies have long investment time horizons (i.e., 40–50 years) similar to that of a hydropower plant to match their pensioner disbursement time frame (Office of Energy Efficiency and Renewable Energy 2004). Notably, Public Sector Pension Investment Board has had an ownership stake in H2O Power[46] since 2011.

Surveyed institutional investors indicated that they were open to investing in medium-sized hydropower or PSH in the next 5 years.[47] There were a variety of interests in NPDs, capacity additions, closed-loop PSH, and combined renewable energy projects. However, none of the institutional investors found open-loop PSH an interesting investment opportunity.

5.2.3 Private Equity and Venture Capital Funds

Across the energy sector (both renewables and nonrenewables), PE and VC firms invested around $617 billion across almost 3,000 energy companies from 2012 to 2023 (American Investment Council 2023). Specifically for clean technology energy companies, PE and VC firms invested more than $136 billion from 2012 to 2023, with investments in clean technology representing a growing percentage in recent years (American Investment Council 2023).

The PE and VC funds typically invest equity into startup and established companies over a time horizon of approximately 4 to 7 years (which can vary depending on type and fund). PE funds generally seek investments that generate stable cash flows where they can identify and recognize operating efficiencies. Alternatively, VC funds usually prefer investments that help them monetize rapid growth of large new markets. Both investor types often focus their investments on a particular set of target sectors and invest capital on behalf of qualified investors (limited partners). Both funds invest in startup companies at various stages, from pre-seed through seed, series, growth, and expansion stages.

PE and VC firms have made significant recent corporate investments into innovative new technology suppliers, conduit project developers, and equipment manufacturers. More recently, they have invested in hydropower and PSH assets because these assets contribute to their ESG or renewable energy requirements. For example, one interviewed PE firm decided to begin investing in hydropower because they view it as a good opportunity to take advantage of preexisting infrastructure that USACE has carefully maintained. The firm plans to decide whether to continue investing based on the outcome of its initial set of investments.

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[46] https://www.h2opower.com/

[47] This survey is illustrative, rather than exhaustive, due to its limited sample size (four institutional investors responded).

Case Study: Partnership Between Climate Adaptive Infrastructure (CAI) and Rye Development Enables Successful Hydropower Project Development

In 2021, Rye Development, a hydropower developer, announced that Climate Adaptive Infrastructure (CAI), a PE fund, committed to fund $150 million for the development of 22 NPDs, mainly on existing USACE locks in the eastern United States, with a total generation capacity of 250 MW (Hydro Review 2021a; IPE Staff 2021). In an interview with Rye, leadership mentioned that their past project experience enables them to effectively navigate the complex 10-year process of conception, licensing, financing, construction, and sale of hydropower project developments.

Figure 22. Emsworth Lock and Dam near downtown Pittsburgh, Pennsylvania—an NPD that Rye plans to retrofit to add 20 MW in generation capacity. Photo from Rye Development (2023)

In an interview with IPE, Bill Green, partner at CAI, noted that the company decided to invest in Rye because "[Rye] is a perfect fit with CAI's mission to fund large-scale, low-carbon infrastructure projects that withstand the policy risks and economic pressures of the global climate crisis" (IPE Staff 2021). CAI leadership noted in an interview that the reemerging hydropower field posed a good opportunity for CAI due to the ability to retrofit preexisting infrastructure that has been well maintained by USACE. Rye increases the appeal of medium-sized hydropower by bundling projects to secure investment and sell to operators. Bundling serves the dual purpose of increasing the investment value, often increasing its appeal to investors and de-risking the investment through portfolio diversification. Renewables developers seeking investment can use Rye and CAI's partnership as an example for how to strategically grow hydropower assets to support a cleaner grid.

Table A-2 in Appendix A provides an overview of 17 recent medium-sized hydropower and PSH transactions (2013–2023) carried out by PE and VC funds. These are the key takeaways:

- **Transaction Types**: Of identified transactions, PE and VC funds carried out six acquisitions, two infrastructure investments, and nine corporate investments in the last 10 years. This quantity of transactions matches that of project developers and IPPs during the same time frame, underscoring the importance of PE and VC firms in supporting market growth. PE/VC firms have been active in making direct corporate investments into developers, equipment manufacturers, and product suppliers, demonstrating interest in innovative solutions around hydropower technology and energy platforms. For example, several new and innovative companies (like Emrgy, Natel, and Serium) raised corporate investment from institutional and PE/VC investors. Equity investments in a company also help to minimize risks that would be present for project-specific investments, as company risks are more diversified than project-specific risks.

- **Investor Diversit**y: Thirteen PE and VC firms carried out 17 transactions, indicating investment interest from a diverse group of firms. Many corporate investments were carried out in partnership with other PE/VC firms, which may reflect the desire of PE/VC firms to de-risk their corporate investments through the use of partnerships.
- **Trends Over Tim**e: Like project developers and IPPs, more than half of the transactions occurred from 2020 to 2023, which may suggest more recent momentum for hydropower market activity and present an optimistic picture for future PE/VC market involvement in the coming years.

5.2.4 Utilities and Community Choice Aggregators

The transaction analysis shows that utilities, which can be investor-owned, publicly owned, or member-owned cooperatives, are also active in the medium-sized U.S. hydropower market. Though there are fewer investor-owned utilities (172) than publicly owned utilities (1,963) and cooperatives (812) in the United States, investor-owned utilities tend to be larger and serve more than 70% of customers (Homeland Infrastructure Foundation-Level Data 2023; EIA 2019).

Depending on what regulators allow utilities in vertically integrated markets can invest in generation projects or may use competitive procurements to acquire new power supplies. In these competitive processes, hydropower and PSH are competing with wind, solar, and other generation technologies. Utilities can finance projects that their regulators and members would consider to be prudent investments. While regulators may ultimately view hydropower to be a prudent investment, the utility often must justify investing in generation as compared to purchasing renewable energy in a competitive tender with no investment risk. Because regulated utilities must answer to regulatory commissions, higher power generation costs (Section 4.2.1) for medium-sized hydropower projects, compared with wind and solar, limit the interest of utilities and non-utility power generators to invest in hydropower and PSH projects. To increase the interest, a utility could compare (in addition to cost) the complementary benefits of hydropower and PSH with wind and solar, to justify higher investments. A utility must also often justify investing in generation instead of spending on other activities (e.g., reconductoring, metering, transformer replacement, and/or a host of measures concerning reliability, cost of service, safety, and climate change readiness).

The concept of Community Choice Aggregators (CCAs) is a recent development. Presently, CCAs are authorized in 10 states and are under consideration in an additional five states[48] (LEAN Energy 2023). CCAs obtain electricity for their customers from different sources while continuing to use the utility company's transmission and distribution services. As such, CCAs can act as buyers of hydropower generation rather than direct project investors. The CCA portfolios to date purchase a majority of power from wind energy generators, but CCAs in California, Illinois, and Massachusetts purchase electricity generated from hydropower for their members (O'Shaughnessy et al. 2019). Often, CCA customers want control over the source of

[48] Ten states have already enacted CCA legislation: California, Illinois, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Rhode Island, and Virginia. Five additional states are in various stages of drafting CCA-enabling legislation: Arizona, New Mexico, Colorado, Michigan, and Pennsylvania (LEAN Energy 2023).

their electrical power generation, preferring renewable and local resources. Some CCAs are also exploring commitments or investments in electric vehicle charging, further embodying an end-to-end local supply chain for energy. Redwood Coast Energy Authority (RCEA) provides an example of a CCA facilitating locally controlled development (Paulson 2021). Filings note that the CCA's "official board-approved preferred portfolio will include a total of 14 MW of small hydro by 2030. … small hydro [is] one of its 'more expensive RPS resources,' alongside biomass; however, RCEA said it recognizes the benefits of having a diverse portfolio, community benefits associated with these local resources, and these resources' contributions to reliability" (Paulson 2021). Efforts like this to promote local development of sustainable resources by CCAs have potential to support future small and medium-sized hydropower development.

Some utility companies and CCAs also support new investment in hydropower and PSH capacity by signing PPAs with IPPs and project developers for projects in their service territory. As discussed in Section 3, long-term PPAs with local utility companies can support project developers in raising external financing to support hydropower project construction.

Comments obtained from the survey suggest that utilities are unlikely to prioritize investments in new hydropower generation but are interested in capacity additions for existing owned assets. Of the utilities surveyed, almost half expressed an openness (positive response or "maybe") to developing medium-sized hydropower and PSH over the next 5 years.[49] One utility who responded "no" shared that they had tried several times over the years to justify adding capacity to existing powered dams and NPDs, but the projects always failed to pass the cost-benefit analysis. Among the utilities surveyed who plan to develop hydropower in the next 5 years, most are only interested in capacity additions with little interest in any of the other types of projects.

Table A-3 in Appendix A provides an overview of 10 recent medium-sized hydropower and PSH transactions (2013–2023) carried out by utilities. Key takeaways include:

- **Transaction Types**: Of identified transactions, utilities were very active in the infrastructure investment space, with seven infrastructure investments and three acquisitions. Of infrastructure investments identified, there was an even distribution between hydropower projects that add capacity (NPD retrofits and capacity additions) and refurbishment of existing hydropower facilities. NPD retrofits mainly occurred in areas more amenable to hydropower than other renewables; for instance, Alaska Power & Telephone commissioned the 5 MW Hiilangaay Hydro Project on Prince of Wales Island in Alaska, which experiences limited daylight hours in the winter (Thayer 2023).
- **Investor Diversity**: No single utility was responsible for more than one of the researched transactions, suggesting relatively high diversity in the utilities investing in hydropower. Most active utilities were relatively small publicly owned utilities and cooperatives rather than investor-owned utilities. They generally made targeted investments in local assets. This pattern may reflect publicly owned utilities and cooperatives' interests in developing

[49] This survey is illustrative, rather than exhaustive, due to its limited sample size (10 public and private utilities responded).

and maintaining community hydropower assets, as they do not have the ability to access the variety of generation sources that larger, investor-owned utilities do.

- **Transaction Detail**s: Aside from Hydro Quebec's acquisition of Great River Hydroelectric Facilities, none of the other three acquisitions performed by utilities were of portfolios of assets. This may indicate that utilities are more interested in making select hydropower infrastructure acquisitions that are compatible with their grid network rather than considering acquisitions more broadly like private project developers/IPPs. Of the eight transactions in the United States, half were made in vertically integrated markets while the other half were made in restructured markets.
- **Trends Over Tim**e: Like project developers/IPPs and PE/VC funds, more than half of the transactions occurred from 2020 to 2023, which may suggest more recent momentum for hydropower market activity and present an optimistic picture for future utility and CCA investments and commitments in the coming years.

5.3 Profiles of Potential Future Investors in Hydropower and PSH

Commercial banks providing traditional lending (debt) and tax equity investors have not been active in the U.S. medium-sized hydropower and PSH market over the past decade, but these investors shared potential interest in future investments if incentives and economics align for a pipeline of bankable projects. The sections below discuss both types of investors. Many tax equity investors are large commercial banks, but the motivations for traditional lending compared to tax equity financing are very different. Therefore, this section presents the two profiles separately.

5.3.1 Commercial Banks

Commercial banks and traditional project finance have been largely absent from recent investments in medium-sized hydropower and PSH projects. As commercial banks mentioned during interviews, they have been absent primarily due to the elongated timelines of hydropower development, lack of long-term PPAs, variance in hydropower and PSH valuations, and the medium-sized projects not providing a large enough deal size to offset transaction costs, among other reasons. By comparison, a recent study found that banks provided $178 billion in loans and bond underwriting globally to wind and solar from January 2016 to July 2022 (Cleaveland 2023).

Banks seek to deploy capital at terms and rates that align to their cost of capital, maturities of their balance sheet obligations, and the risk profile of the borrower. Commercial banks interviewed shared their interest in larger transactions given their fixed transaction costs. A bank's minimum transaction (ticket) size can vary widely, but many large commercial banks interviewed prefer deals at least $25–$50 million in size. This preference has historically limited their level of interest and engagement with smaller hydropower and PSH projects to large corporate loans to investor-owned utilities. Banks are typically technology-agnostic and finance a variety of infrastructure, including hydropower and PSH. However, commercial banks interviewed as part of this report indicated interest in investing if USACE, as the owner of most dams in the United States, could survey, rank, and bundle the NPD assets prime for investment, enabling investors to invest in portfolios of projects. Commercial banks emphasized that bundling would allow for larger investment sizes, helping them meet requirements from their credit committees while also diversifying individual project risks via a portfolio (or bundle) of assets.

Based on their risk profile, interviewed commercial banks that are active in the project finance market expressed interest in investing in projects with low revenue risk (a bankable PPA) and in investing at a time close to project construction when risks are lower compared to earlier-stage project development. To meet needs earlier in the project development life cycle, financing from U.S. federal agencies could help move projects from concept to construction and catalyze construction-stage investment from commercial banks and other investors discussed previously.

Interviewed and surveyed stakeholders mentioned that commercial banks provide financing for various other energy sectors, including a long legacy with financing fossil fuels, but there is a growing interest in transitioning portfolios and investing in renewables to align with climate goals and ESG requirements. However, although PSH has significantly lower life cycle greenhouse gas emissions than battery-based storage (Simon et al. 2023) and run-of-river hydropower and PSH have lower life cycle greenhouse gas emissions than solar (NHA 2021; Woolf 2021), investors may be hesitant to invest in hydropower of any size because certain states like California do not classify large hydropower as clean energy (California State Senate 2023). From a climate impact perspective, it is unfortunate that hydropower and competing technologies are not considered holistically in many greenhouse gas assessments. This is another gap in valuation methods (i.e., if the goal is to reduce carbon, then we should be assessing each technology's overall carbon impact), and this point was reinforced by survey participants in direct comments. On the other hand, California's Senate Bill 100 outlines clean energy targets[50] and existing zero-carbon dams as clean energy (California State Senate 2023). These differing interpretations and understanding of what is or is not "clean" energy could dissuade banks trying to meet clean energy targets from investing in hydropower and incentivize them to invest instead in commonly accepted "clean" technologies like wind or solar.

As part of the growing interest in ESG lending from commercial banks and the financial sector at large, green bonds have recently received attention as a financial instrument for renewable energy investing. Figure 22 provides a brief spotlight on today's green bond market.

SPOTLIGHT ON: **GREEN BONDS**

The energy transition from fossil fuels to renewable sources is bringing attention to ESG concerns, including an increased demand for **green bonds**. Green bonds are fixed-income instruments that raise capital to fund projects that benefit the environment, such as those related to renewable energy like hydropower and PSH. Since the purposes of these bonds are specified, green bonds are considered "use-of-proceeds" bonds, where proceeds are spent on specifically identified projects.

Other, key performance indicator-linked bonds, like those in the Pay for Success/Social Impact Bond markets can also target renewable energy and environment projects. These bonds follow a public-private-partnership type model in which an impact investor receives an intern on investment if the project meets certain KPIs, as measured by a third-party evaluator.

While green bonds are important for ESG investing, they currently represent less than 3% of global bonds (Deloitte 2023). However, improvements in regulating and reporting green bond issuances in the United States will further spur their growth.

Figure 23. Green bonds spotlight

[50] Specifically in California, small hydropower includes facilities smaller than 30 MW (California Energy Commission 2023).

Due in part to low installed costs and relatively simpler project development processes for solar and wind, many banks have focused recent investments within renewable energy on the solar and wind markets, particularly given these technologies' frequent use of the tax equity and REC markets. Various commercial banks interviewed shared that, while they have not been active investors in medium-sized hydropower recently, they are open to advising on project financing or investing if project economics are bankable and risks minimized. For example, a commercial bank survey respondent shared that, in the future, they would consider serving as bond trustee, escrow agent, and collateral agent for hydropower projects. Given increasing motivations for clean energy investments and new incentives from the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA), interest from banks to invest in hydropower could increase in the coming years.

5.3.2 Tax Equity Investors

Tax equity investors provide structured equity investments in exchange for a combination of tax credits guaranteed by the U.S. Treasury and dividend payments from a project (as available). Many renewable energy project developers commonly use tax equity structures today, but solar and wind have historically been the most active for this type of investment. The tax equity market represents a $20 billion annual market today, which, according to industry, will need to increase to a $50 billion annual market to meet the goals of the IRA (American Council on Renewable Energy [ACORE] 2023). Each tax equity transaction can have unique structures but typically could include a transfer of tax credits, tax deductions such as those related to accelerated depreciation deductions, and cash flows. The amount of equity provided in a project depends on the project specifications and the agreement with the tax equity investors, but generally can be around 35% of project costs (Martin 2022).

As of 2021, the Internal Revenue Service (IRS) provided investment tax credits (ITCs) and production tax credits (PTCs) for approximately 170 hydropower projects, amounting to an estimated $10 million to $35 million annually (Strong 2021), equivalent to less than 10% of the $1 billion annually in tax credits that wind and solar projects received (Strong 2021). Prior to IRA-mandated changes that went into effect in January 2023, the PTC offered hydropower projects a tax credit rate equal to half that of wind projects (Pisano 2022). With passage of the IRA, PTC rates are now equivalent across generation types. Pressurized conduits are now newly eligible for the PTC in addition to capacity upgrades and NPD retrofits, which were already eligible. In addition, the IRA created an energy storage ITC, which supports new development and capacity additions to PSH and other energy storage facilities. Due to the recency of the passage and implementation of the IRA, it is challenging to assess the impact it will have on hydropower development.

A recent Notice of Proposed Rulemaking (NPR) from the Federal Deposit Insurance Corporation (FDIC) could have significant negative impact on the tax equity market for all renewable energy projects, including hydropower, despite the tax credits in the IRA. The NPR, dated July 27, 2023, proposes to revise the measurement of risk-weighted assets to determine the credit risk for large banks (total assets of $100 billion or more), their subsidiary depository institutions, and other banks with significant trading activity ($5 billion or more in trading asset) (FDIC 2023). The NPR proposes increasing the risk-weighted asset requirement by fourfold for equity exposures that investors do not publicly trade, which makes up the majority of the renewable energy tax equity market (FDIC 2023). A letter from ACORE, signed by industry representatives, notes that the rule "could severely reduce banks' capacity in providing tax equity" (ACORE 2023).

Tax equity investors typically commit to tax liabilities with short horizons (up to 2 years), which can make it difficult for long-lead-time projects like hydropower to secure tax equity because the government will not provide credits until the year the project is in service (and investors are not likely to provide a long forward commit). During a stakeholder interview, a tax equity professional shared that banks typically commit their liabilities 2 years out and have likely already committed their tax liability in the short term for 2023 and 2024.

6 Potential Opportunities for DOE To Address Key Barriers

The federal government and DOE play a critical role in championing the development of the hydropower industry today. Stakeholders shared additional potential solutions or actions for DOE consideration to further address key barriers impacting their appetite to develop or invest in medium-sized hydropower and PSH. This section provides an overview of incentives from the federal government available for hydropower projects, reviews current initiatives led by the DOE, and discusses other potential solutions shared by stakeholders to address the identified and entrenched barriers.

6.1 Current Initiatives and Incentives for Hydropower and PSH

6.1.1 Federal Incentives

The federal government supports hydropower development and other renewables primarily in the form of tax credits, incentives, grants, debt, and loan guarantees. There has been a fundamental transformation of federal funding with the IIJA passed in November 2021 and the IRA passed in August 2022, which include billions of dollars in appropriated funding for programs for which hydropower and PSH development qualify. These initiatives represent an unprecedented funding opportunity for these technologies. The incentives programs run by federal agencies and offices described below have the potential to support and catalyze significant future investment in hydropower and PSH projects. Table B-1 in Appendix B provides a list of these incentives and others relevant to medium-sized hydropower and PSH.

6.1.1.1 DOE Grid Deployment Office

The DOE Grid Deployment Office (GDO) administers several hydropower-specific incentive programs to promote hydropower development with explicit beneficial outcomes (GDO 2023a). In stakeholder conversations, one developer noted that their 30-MW run-of-river hydropower project became bankable due to these federal incentives, described below:

- **Hydroelectric Production Incentives (Energy Policy Act [EPAct] Section 242).** This program provides $125 million through the latest appropriations from the IIJA in incentive payments for electricity generated and sold from new or expanded hydroelectric facilities specifically for NPDs, conduits, and capacity additions, with particular emphasis on those in communities with inadequate electricity provision, called “energy communities” (GDO 2023c). The program was first authorized through the EPAct in 2005, but Congress did not allocate direct funding to the program until 2014 (GDO 2023e). Since 2014, the program has received annual appropriations (GDO 2023e). On October 11, 2023, GDO announced the latest incentive payment recipients through this program, which included a disbursement of more than $38 million across 66 hydropower facilities (GDO 2023e).
- **Hydroelectric Efficiency Improvement Incentives (EPAct Section 243).** This program provides $75 million via the IIJA in incentive payments for existing hydropower and PSH facilities to make capital improvements to improve efficiency by at least 3% (GDO 2023d). Section 243 was also authorized through the EPAct in 2005 but did not receive funding until the IIJA (GDO 2023d).

- **Maintaining and Enhancing Hydroelectricity Incentives (EPAct Section 247).** This program provides $554 million in incentive payments via the IIJA specifically for capital improvements on existing hydropower projects that impact grid resiliency, dam safety, and environmental improvements (GDO 2023b). The initial window for applications closed on October 6, 2023 (GDO 2023f).

DOE's hydropower-specific incentives are key to helping hydropower compete with other renewables that can obtain general renewable incentives more easily. One project developer noted in the survey that they are extremely likely to take advantage of incentives provided by Sections 242, 243, and 247 to compete with the incentives wind and solar receive. As Figure 23 shows, of 11 surveyed project developers, the majority are likely to use Section 242 and Section 247 to support development.

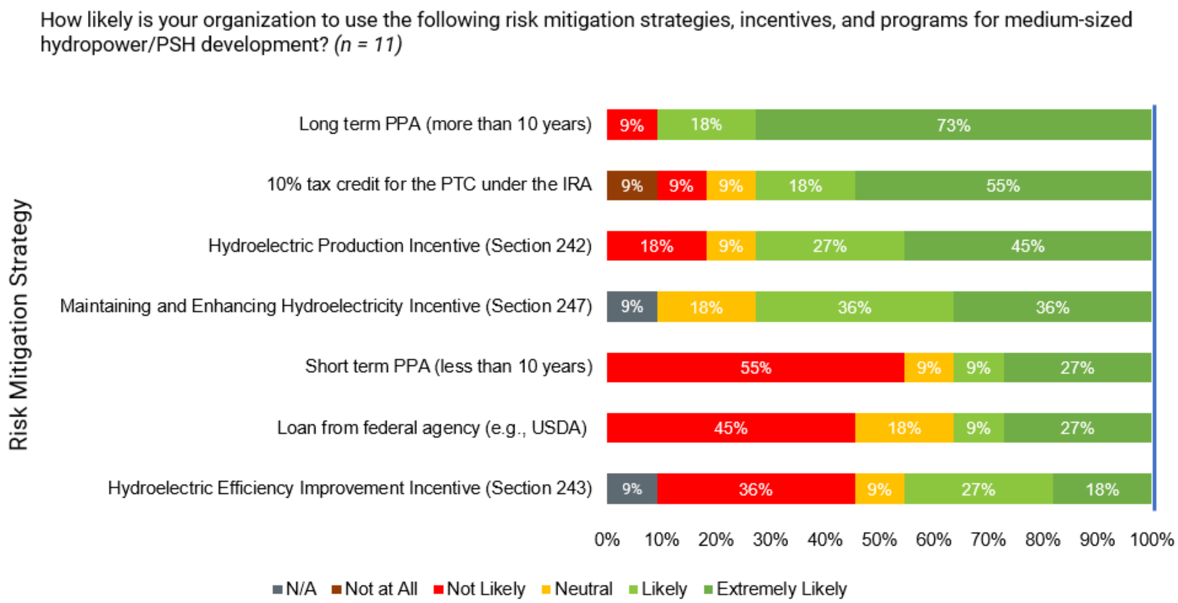

Figure 24. Risk mitigation strategies for developers

6.1.1.2 DOE Loan Programs Office

The LPO provides loans and loan guarantees to innovative energy projects and often helps catalyze investment from private lenders that would otherwise not be available due to the risk profile of a project (LPO 2023b). This financing includes long-term, senior debt funding that can be structured as project finance debt, a corporate loan, or a hybrid structured product to support the construction of clean energy projects including hydropower. As of July 2023, LPO had more than 157 active applications for projects across all regions of the United States totaling nearly $139 billion in requested loans and loan guarantees (LPO 2023c). While LPO has not funded hydropower projects to date, LPO representatives shared their interest to do so during NHA's 2023 Waterpower Week conference. Projects incorporating new technologies—like new technologies for PSH such as submersible pump-turbines and motor-generators, geomechanical PSH, open mine pits, or modular PSH and conduits—could provide an opportune use case for LPO financing to catalyze the hydropower and PSH markets if LPO applicant requirements are met.

The IRA also recently established the LPO Energy Infrastructure Reinvestment Loan Program, which provides direct loans and partial guarantees to bolster energy infrastructure reinvestment across the United States, including in designated DOE energy communities, as an addition to LPO's Title 17 Clean Energy Financing Program. The IRA appropriates $5 billion through September 2026 to support loan guarantees up to $250 billion for projects that retool, repower, repurpose, or replace inactive energy infrastructure. Hydropower and PSH projects could be eligible for this program (LPO 2023a).

6.1.1.3 DOE Office of Clean Energy Demonstrations

The DOE Office of Clean Energy Demonstrations (OCED) provides grants to help demonstration projects that center on the development of innovative long-duration energy storage technologies to achieve commercial viability. The OCED Program on Current and Former Mine Land received $500 million from the Bipartisan Infrastructure Law for projects that address resolving key barriers to clean energy development on mine land, repurposing mine land for clean energy projects, preserving natural resources, and integrating community benefits and near net-zero mining for clean energy on mine land (OCED 2023d). This funding, applicable for both grants and technical assistance, will be available through 2026 and could be an opportunity for PSH projects.

6.1.1.4 DOE Office of State and Community Energy Programs

The DOE Office of State and Community Energy Programs (SCEP) is a newly created office (since November 2022) dedicated to providing self-sustaining clean energy projects by working with state energy offices, Tribal nations, territories, local governments, local education agencies, nonprofit organizations, and community organizations (SCEP 2023). SCEP manages $16 billion in grants, awards, prizes, and technical assistance to deploy for clean energy projects (SCEP 2023). Hydropower may be eligible for some of these funds.

6.1.1.5 Federal Tax Credits

The IRS administers a variety of tax credits to help incentivize investment in priority areas. Two tax credits can be leveraged for hydropower and PSH development:

- The **Production Tax Credit** awards $5.50/MWh to $33.00/MWh of electricity produced and is applicable to "capacity upgrades at existing hydropower facilities, retrofits of [NPDs] with hydropower generation, and new marine energy projects," and pressurized conduits (WPTO 2023a; Pisano 2022). The credit rate depends on project size, compliance with wage and apprenticeship requirements, and qualification for the energy community bonus and/or domestic content bonus.
- The **Investment Tax Credit** for energy property offers a 6% to 50% tax credit for the cost of building renewable energy systems, including PSH, or for qualified facilities under the PTC (see above) in lieu of PTC credits (WPTO 2023a). Credit rate depends on project size, compliance with wage and apprenticeship requirements, and qualification for the energy community bonus and/or domestic content bonus.

As of January 2023, the IRA updated PTC and ITC provisions to make them more applicable to hydropower investors. However, the ITC will expire in 2033, though safe harbor guidance will provide eligibility for an additional 5 years. Developers can take advantage of these new provisions to bring down the cost of hydropower in the same way that wind and solar developers have been using the PTC and ITC for years.

6.1.1.6 USACE Core Water Infrastructure Financing Program

As a major owner and operator of dams in the United States, USACE administers a loan program to support dam maintenance that can be leveraged to support hydropower development. The CWIFP is a new federal loan program which has received $81 million for credit subsidy and an additional $22.6 million for program administration. CWIFP finances projects that maintain, upgrade, and repair dam infrastructure across the United States and is limited to nonfederal dams (USACE 2023a).

6.1.1.7 U.S. Department of Agriculture Funding Opportunities

The U.S. Department of Agriculture (USDA) offers a range of funding opportunities, including grants and partially forgivable loans, to advance rural clean energy initiatives. The IRA provided funding for several USDA programs, including the following ones relevant to hydropower:

- The **Powering Affordable Clean Energy (PACE)** program allocates $1 billion from the IRA to propel clean energy projects. The program forgives up to 60% of loans for utility-scale clean energy projects (USDA 2023b).
- The **Empowering Rural America (New ERA)** program provides $9.7 billion through September 2031 to rural electric cooperatives through loans, grants, and loan refinancing to support energy efficiency improvements, deploy zero-emission systems, or purchase renewable energy (USDA 2023a).
- The **Rural Energy for America Program (REAP)** "provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses for renewable energy systems or to make energy efficiency improvements" (USDA 2023c). Eligible projects include medium-sized hydropower in rural areas with populations of 50,000 residents or less. The program provides $1 billion from the IRA in FY23 and FY24 (USDA 2023c).

The federal agency incentive programs listed above could be important for the advancement of medium-sized hydropower and PSH projects. They have the potential to provide financial support and technical expertise to de-risk early-stage development, attract private investment, and accelerate the deployment of these clean energy solutions. Through tax credits, funding opportunities, and targeted support, these incentives and those described in Appendix B have the potential to enhance project viability, thus eventually encouraging private investment.

6.1.2 Current WPTO-Led Initiatives Related to Hydropower and PSH

In addition to the incentives and programs described above, WPTO has led several initiatives aimed at increasing hydropower and PSH development in the United States.

WPTO's MYPP, released in 2022, outlines strategic approaches and outcomes to achieve its mission through 2030 (DOE 2022). The MYPP states that the hydropower program's mission is to "conduct research, development, demonstration, and commercial activities to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and PSH technologies; better understand and capitalize upon opportunities for these technologies to support the nation's rapidly evolving grid; and improve energy-water infrastructure and security" (DOE 2022). In line with this mission, WPTO has established a number of long-term outcomes it aims to achieve, including deployment of new hydropower and PSH projects that are cost competitive and integrate multiple social, ecosystem, and energy needs. Its efforts center on five main themes: (1) innovations for low-impact hydropower growth; (2) grid reliability, resilience, and integration; (3) fleet modernization, maintenance, and cybersecurity; (4) environmental and hydrologic systems science; and (5) data access and analytics.

To achieve the mission and outcomes set forth in the MYPP, WPTO has produced an extensive set of resources aimed at supporting hydropower and PSH market growth. WPTO's research efforts culminate in the production of analysis and guidance reports to inform developers and investors of market, technological, and other opportunities. The WPTO also leads the development of interactive toolkits that provide developers with tactical resources to guide them through the complex hydropower development process. Table 8 provides a snapshot of resources that developers and investors can leverage to support growth of medium-sized hydropower and PSH assets.

Table 8. Recent and Ongoing Hydropower Research Initiatives From DOE and National Laboratories

Resource	Type and Purpose
A Review of Technology Innovations for Pumped Storage Hydropower	Analysis report that "evaluates innovative PSH technologies to provide an objective third-party assessment of their key features, capabilities, and parameters" (Koritarov et al. 2022).
Advanced Hydropower and PSH Capacity Expansion Modeling	Analysis report that provides "initial insights into what is most important for analysts, electricity system planners, and hydropower decision makers to consider when assessing future roles of hydropower and PSH" (Cohen and Mowers 2022)
Compensation Mechanisms for Long-Duration Energy Storage	Analysis report that reviews "emerging long duration energy storage compensation and business models from around the world, drawing insights for the United States in terms of regulatory, policy, and market design implications" (Bhatnagar et al. 2022).
Cost Analysis of Hydropower Options at Non-Powered Dams	Analysis report that "provides hydropower developers with better insights into the potential costs of adding hydropower generation capability or powering existing [NPD] projects and explores ways to reduce costs" (Oladosu, George, and Wells 2021).
Energy Storage Technology and Cost Characterization Report	Analysis report that "defines and evaluates cost and performance parameters of six Battery Energy Storage System (BESS) and four non-BESS storage technologies" (Mongird et al. 2019.)
Hydropower Market Reports	Analysis reports that review developments in the U.S. hydropower and PSH fleet and industry trends (WPTO 2023c).
Hydropower Plants as Black-Start Resources	Analysis report that identifies advantages of using hydroelectric power for black start and compares

Resource	Type and Purpose
	hydropower with other black-start power plant technologies (Gracia et al. 2019).
Hydropower: Supply Chain Deep Dive Assessment	Analysis report that examines hydropower supply chain to identify potential bottlenecks, challenges, and opportunities (Uría-Martínez et al. 2022).
Hydropower Vision	Goal-setting report with “comprehensive analysis to evaluate future pathways for low-carbon, renewable hydropower (hydropower generation and pumped storage) in the United States, focused on continued technical evolution, increased energy market value, and environmental sustainability” (DOE 2016).
Designing Hydropower Flows to Balance Energy and Environmental Needs	Guidance report that “aims to create building blocks for the future science and tools all parts of the hydropower community involved in regulatory proceedings will need to balance energy and environmental objectives through flow management” (Pracheil et al. 2022).
Enabling Principles for Dual Participation by Energy Storage As a Transmission and Market Asset	Guidance report that “details characteristics that allow energy storage assets, such as [PSH], to provide two distinct services to the electric grid: regulated transmission and acting as a competitive energy market” (Twitchell et al. 2022).
Non-Powered Dam Retrofit Exemplary Design for Hydropower Applications	Guidance report that identifies best practices to guide development activities and identifies opportunities to achieve non-energy benefits (DeNeale et al. 2022).
Pumped Storage Hydropower Valuation Guidebook: A Cost-Benefit and Decision Analysis Valuation Framework	Guidance report with “detailed step-by-step valuation guidance that PSH developers, plant owners or operators, and other stakeholders can use to assess the value of existing or potential new PSH plants” (Koritarov et al. 2021).
Closed-Loop Pumped Storage Hydropower Resource Assessment for the United States	Resource assessment report that “seeks to better understand the technical potential for PSH development in the United States by developing a national-scale resource assessment for closed-loop PSH” (Rosenlieb, Heimiller, and Cohen 2022).
An Assessment of Hydropower Potential at National Conduits	Resource assessment report reviewing potential for new hydropower development on conduits nationwide across municipal, agricultural, and industrial sectors (Kao et al. 2022).
PSH Valuation Tool	Decision tree-based tool to help developers, owners, and other stakeholders assess the value of PSH projects. The tool considers PSH factors such as the value of bulk power capacity, the value of energy arbitrage, value of production cost reductions, value of ancillary services, power system stability benefits, and transmission benefits. Link: https://pshvt.egs.anl.gov/
Biological Performance Assessment (BioPA)	Assessment tool using “computational models to evaluate relative impact that passage through a given hydropower turbine can have on a species of fish.” Link: https://www.pnnl.gov/projects/hydropassage/biopa

Resource	Type and Purpose
Hydropower Cybersecurity Value-at-Risk Framework	Self-guided, automated tool to make sound cybersecurity investment decisions for individual facilities (Sanghvi et al. 2023).
Hydropower RAPID Toolkit	Hydropower regulatory and permitting information desktop toolkit. Link: https://openei.org/wiki/RAPID/Hydropower
HydroSource	Comprehensive "National Energy-Water digital platform designed to help the hydropower community make data-driven decisions." Link: https://hydrosource.ornl.gov/
NPD Explorer App	Interactive platform that allows researchers and developers to explore NPD development opportunities in the United States. Link: https://ornl.maps.arcgis.com/apps/webappviewer/index.html?id=4756decebce4408ba4bc0a0c3dc23a5f
River Function Indicator Questionnaire	Questionnaire tool that provides hydropower stakeholders with systematic and transparent method for identifying potential project environmental impacts. Link: https://rfiq.ornl.gov/
Water Allocation Tool Enabling Rapid Small Hydropower Environmental Design currentlyD) tool	Design tool that "aims to reduce time and money developers must spend evaluating the design, operation, and feasibility of new, small hydropower projects at streams and sites with existing water infrastructure like [NPDs]." (Available on GitHub: https://github.com/waterSHED-Model-ORNL/waterSHED-Model).

Sources: Descriptions of each document's purpose are from the WPTO website. Additional projects are on the Water Power Technologies Office Projects Map (WPTO 2023b).

Table 8 is not an exhaustive list of the support that DOE and the national laboratories provide to increase deployment of hydropower but outlines key recent initiatives to highlight the type of support DOE and the national laboratories could continue to provide in the future. Investment-focused reports like this one can complement WPTO's technical research focus established in its mission in the MYPP, emphasizing critical investment enablers needed to successfully deploy innovative and sustainable hydropower technologies. In addition, DOE provides a range of appropriate research and technology funding.

6.2 Overview of Stakeholder-Recommended Solutions

Figure 24 outlines potential priority areas of support that stakeholders identified during interviews and survey responses and highlights their relation to key barriers, project types, and investor profiles. While Figure 24 does not include an exhaustive list of all possible solutions to address the key barriers outlined in Section 4, it does highlight solutions selected based on stakeholder input for priority consideration. In addition, Figure 25 and Figure 26 provide investor and developer survey responses, respectively, that support prioritization of the key solutions to address investment barriers.

Through interviews and survey results, stakeholders identified six key areas to support investment and market growth: (1) provide financing, funding, and support for early-stage development; (2) support improved market-based incentive signals for hydropower and PSH; (3) support more transparent and efficient permitting and licensing processes; (4) support new, innovative research on reducing deployment costs; (5) clarify new legislation and regulations and conduct outreach with developers and industry; and (6) increase awareness of new opportunities in hydropower.

Potential Priority Area for Support	Key Barrier to be Addressed						Project Type Applicability				Solution's Impact to Potentially Unlocking Investment from Investors					
	Long Development Timelines	Lack of Access to Early-Stage Funding	Challenges in Securing PPAs	Inadequate Market Compensation	High Development Costs	Limited Industry Awareness	Powering NPDs	Capacity Additions	Conduit Development	PSH	IPPs/ Project Developers	Institutional Investors	PE/VC Funds	Utilities	Commercial Banks	Tax Equity Investors
Provide Financing, Funding, and Support for Early-Stage Development		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	
Support Improved Market-based Incentive Signals for Hydropower and PSH				✓	✓		✓	✓	✓	✓	✓	✓			✓	
Support Streamlined Permitting and Licensing Processes	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Support New, Innovative Research on Reducing Deployment Costs		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	
Clarify New Legislation and Regulations and Conduct Outreach with Developers and Industry		✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Increase Awareness in New Opportunities		✓				✓	✓	✓	✓	✓			✓		✓	✓

Figure 25. Overview of potential priority areas and the relation to key barriers, project types, and investor profiles

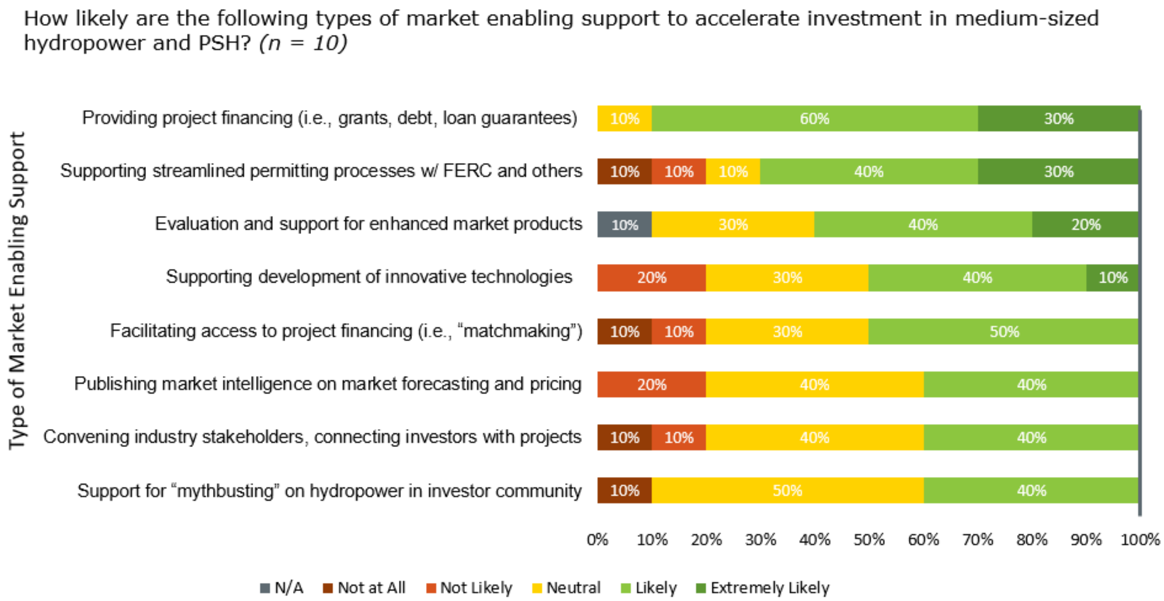

Figure 26. Survey responses from investors regarding market enabling support

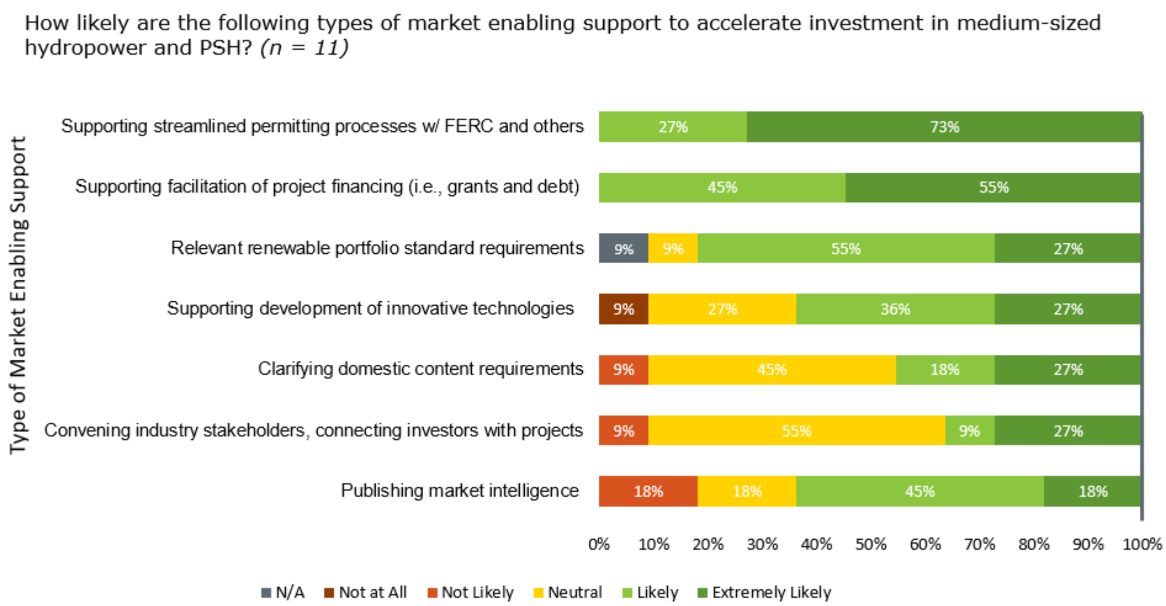

Figure 27. Survey responses from developers regarding market enabling U.S. support

While Figure 25 and Figure 26 represent slightly different questions that cater to either investors or developers, the main takeaways highlight that both investors and developers strongly believe that more transparent and efficient permitting processes and supporting the facilitation of project financing are extremely likely to accelerate investment in medium-sized hydropower and PSH. Additionally, investors believe support for enhanced market products and support for the development of innovative technologies could accelerate investment. Developers believe that relevant RPS requirements and published market intelligence could help accelerate investment. The sections that follow provide additional detail about each of the priority support areas included in Figure 25 and Figure 26.

6.2.1 Provide Financing, Funding, and Support for Early-Stage Development

Various stakeholders that were interviewed and surveyed noted that government assistance in the form of financing, grant funding, and technical assistance could support the success of early-phase hydropower and PSH project development and expand the pipeline of projects. Further, developers are much more bullish on project types like conduits and NPDs, identifying a need for potential awareness of the development advantages to low-impact hydropower within the investment community. Having more defined plans to present to investors will be helpful in securing project investment. Many stakeholders also noted that recent hydropower funding opportunities from DOE had created renewed interest in development. These activities could provide a first step to rapidly deploying hydropower and showcasing the technology effectiveness while working on longer-term activities identified in the sections below.

- **Grants and technical assistance** focused on early-stage development activities before private investors are willing to finance projects, including for developing pre-feasibility and feasibility studies, completing engineering and design studies, testing new technologies, supporting environmental studies/fish passage systems and requisite stakeholder engagement, and preparing licensing and permitting applications, among other activities.
- **Facilitating financing opportunities and supporting documentation preparation,** particularly for new project developers aiming to enter the market. Many new developers need support preparing project documentation sufficient to allow them to successfully approach investors. Template materials, trainings, and technical assistance could support developer preparation and lower barriers to seeking investment for small projects.
- **Loans and/or loan guarantees** provided at below-market rates from agencies such as DOE's LPO or USACE's CWIFP for hydropower and PSH projects would lower the cost of capital for projects and risks for private investment at later stages of the project. Modular conduits, closed-loop PSH, and other innovations might be of particular interest for LPO financing. WPTO could liaise with LPO and USACE to make these instruments available at earlier stages of project development (i.e., before projects can raise debt in the commercial market) to catalyze new development and investment.
- **Coordination with USACE to emphasize the importance of bundling and procuring high-priority NPDs**. This effort could incentivize increased interest to develop and invest in NPDs because bundled projects would increase project size and could expedite licensing and permitting. DOE can use tools developed by Idaho National Laboratory (INL) and ORNL—the NPD Hydro Tool (INL n.d.) and the NPD Explorer (ORNL n.d.), respectively—to build a list of priority NPDs with USACE. By working in partnership with industry, such efforts may produce mutual benefit for both parties.
- **Conduct further analysis on target opportunities and engage corporate PPAs, green banks, CCAs, and ESG investin**g. Innovators in hydropower have shown that corporate agreements provide unique offtake and development opportunities. Further, motivations related to ESG investments are a growing niche market for which low-impact hydropower could potentially be well-suited.

The IIJA sets aside $350 million for demonstration/pilot projects capable of delivering electricity for 10 to 24 hours or longer (Spector 2022). PSH is unique among renewables in its robust long-duration storage capabilities that could align with the requirements for IIJA funding. Furthermore, projects could consider and use other forms of green financing, like green bond structures, as highlighted in Section 5.3.1. Additionally, DOE could help play a role in identifying green investors and introducing them to developers. Such support not only addresses barriers with early-stage development funding but could also help address other areas where projects stall during the planning phase.

6.2.2 Support Market Parity for Hydropower and PSH

Across stakeholder interviews and surveys, a common theme emerged around the value of hydropower and PSH in terms of market parity, particularly across different U.S. wholesale markets (see Section 3). Stakeholder feedback identified the following potential support from DOE:

- **Support stakeholders in addressing environmental profile of hydropower and PSH to bring market parity for low-impact hydropower to increase competitiveness with solar and wind**. Solar and wind have a higher renewable/green classification in many REC markets. Further identifying and defining medium-sized, low-impact hydropower environmental characteristics may support certain markets in redefining hydropower as a green resource equivalent in classification to wind and solar.
- **Enhance supply of grid services enabled by hydropower** by encouraging hybrid projects that incorporate either PSH or batteries at existing facilities to support the plants' ability to smooth variability, take advantage of ancillary services revenues, and manage peak demand, particularly for plants that experience inconsistent hydrology or operate in systems with substantial demand variability. National laboratory models can be used to support further refinement of ancillary services markets.

6.2.3 Encourage Updated Market Models and Valuation Methodologies

Market intelligence may provide clarity for investors and developers and enhance the supply of grid services enabled by hydropower. With greater renewable integration and increased energy deficits, market operators and regulators will need to consider changes to market designs for energy sufficiency and frequency support, which should increase opportunities for hydropower development (Bhatnagar 2022). Stakeholder feedback identified several areas of interest:

- **Help operators address valuation for hydropower and PSH to provide compensation for necessary but currently uncompensated services in power markets.** For example, DOE could consider its role in convening national stakeholders, ISOs, states, federal regulators, and other market actors to promote equitable access and rates in capacity markets for hydropower.
- **Research new market models** to provide support for options that value grid assets. As a greater amount of VRE comes online due to low costs and alignment with carbon mandates, carbon-free options for grid services will become more interesting, as shown by the significant growth in battery storage over the last 5 years. One stakeholder emphasized that DOE may consider modeling a forward capacity market to help system operators identify mechanisms needed to maintain grid stability and to help developers and investors value, plan for, and estimate future investments that may spur market change.

6.2.4 Support More Transparent and Efficient Permitting and Licensing Processes

DOE has identified that NPDs and conduits may offer development advantages over new stream-reach development and has devoted significant efforts to analyze the available resource potential at these sites (Kao et al. 2022; Hadjerioua, Wei, and Kao 2012). Often, these sites offer lower additional environmental impact in the development phase, are more likely to be located near load centers, and have existing infrastructure. Both types of projects present opportunities to pilot efforts to improve the transparency and efficiency of project permitting and licensing processes at the federal (including USACE), state, and local levels. Similarly, closed-loop PSH provides environmental and permitting advantages compared to open-loop PSH, which could provide for expedited permitting and licensing.

While there is strong intent in recent legislation (i.e., to institute 2-year licensing processes for low-impact projects) to decrease the time frame for licensing and permitting, progress on reducing this barrier is still challenging. Efforts by DOE to improve the consistency of these processes and promote effective implementation of these measures was welcomed by the market participants that were surveyed and interviewed. Stakeholder feedback identified the following potential support from DOE and the national laboratories:

- **Review current licensing and permitting queue and identify opportunities** to align permitting and licensing processes and make them more transparent and efficient. Building on the work by Levine et al. (2021), DOE could support a review of the existing queue and identify opportunities for FERC, USACE, and other agencies to improve process efficiency. These efforts could include a review of development challenges that delay the average permit and license application. Similarly, as noted above, DOE could work with USACE and Reclamation or FERC to consider the bundling of certain assets or identify specific sites for regulatory approvals.
- **Review previous relicensing cases** to identify opportunities to improve the transparency and efficiency of future relicensing and reduce risks of license surrenders. Stakeholders mentioned that relicensing can often be as challenging as initial licensing processes, leading some project developers to consider surrendering projects. DOE could review recent relicensing cases to determine if the timeline or costs associated with the relicense rendered a project unbankable and identify ways to reduce this impact going forward.
- **Clarify and highlight expedited licensing processes** under America's Water Infrastructure Act of 2018 for conduits, NPDs, and closed-loop PSH and support project developers attempting to apply with clear written guidance or trainings that specify what projects qualify for expedited licensing. For many low-impact hydropower projects, more efficient and transparent federal processes exist but may need further promotion or clarification to increase use. Additional research is also needed to understand why developers have not used this new process for NPDs.
- **Improve coordination between USACE and FERC to support synchronization of timelines and processes.** Participants interviewed continued to note the number of parties involved in the review process. Where possible, DOE could support coordination and ongoing implementation of the MOU between FERC and USACE to move projects through the development pipeline and align the sequencing of applications and approvals.

- **Differentiate certain aspects of licensing requirements** based on project size (or project type). Various small hydropower developers expressed frustration over the greater lack of consideration of project size for license exemptions beyond 10 MW. A recent NREL study found that larger projects have higher licensing costs overall, but smaller projects on average have higher licensing costs per kilowatt capacity (Levine et al. 2021). For instance, one developer mentioned that developers often take on a few projects but will redirect efforts toward simpler or larger projects because of the high up-front cost of the regulatory processes. DOE could support expanded development of small projects by promoting licensing reforms that expand license exemptions for projects based on size and impact.

If federal agencies can make permitting and licensing processes more transparent and efficient, it would help address many key investment barriers: long development timelines, limited access to early-stage funding, challenges in securing PPAs, and high construction costs.

6.2.5 Support New, Innovative Research on Reducing Deployment Costs

Stakeholders also emphasized that funding critical research is important to modernizing the existing fleet and bringing new technology enhancements to a renewable energy technology that has not received much attention, and as mentioned by an interviewee, there is a significant knowledge gap due to the limited number of at-scale hydropower projects under construction. Stakeholder feedback identified to following potential support from DOE and national laboratories:

- **Continue to fund demonstration projects** to showcase the potential benefits of hydropower and PSH. Projects should specifically highlight innovative technologies, analyze costs, and demonstrate hydropower's value. The Fall River Electric Cooperative and INL's "Microgrid in a Box" provide strong examples of such an initiative, which highlights opportunities for advanced controls for black-start capabilities and demonstrates commercial viability and the ability to serve small/rural communities (INL Media Relations 2023). Such demonstrations can also serve to provide clarity on the regulatory timeline by highlighting new legislative processes and defining where barriers may still exist.
- **Continue to fund research on new and innovative technologies for closed-loop PSH and powering conduits and NPDs** to increase the number of viable investments in projects. Innovative demonstration projects and research should focus on showcasing commercial viability or identifying means to construct projects at a lower cost (including those with new and efficient technologies). Additionally, continuing to fund research into modular development of small conduit hydropower and PSH to decrease siting risks and, eventually, permitting challenges.

6.2.6 Clarify New Legislation and Regulations and Conduct Outreach With Developers and Industry

The majority of stakeholders interviewed emphasized the importance of federal and DOE grants and incentives programs, particularly EPAct Sections 242, 243, and 247, to facilitate the development of medium-sized hydropower and PSH. Many mentioned a renewed appetite in hydropower due to these new incentive programs and an interest in a long-term horizon for these programs. Section 242 incentives can provide payments for electricity generated and sold to offset the costs for hydropower projects already in operation. Hydropower facility owners and operators can use Section 243 incentives to support capital improvements in efficiency. Developers can apply Section 247 incentives to offset the cost of grid resilience, dam safety improvements, and environmental improvements. One developer shared that the grants and tax incentives will serve as a catalyst, and they were actively reviewing opportunities to apply. To fully realize the potential of these incentives to unlock investment, DOE or other government agencies should clarify the following issues:

- **Changes to tax credit eligibility:** As highlighted in Section 6.1.1, the IRA-mandated changes to the tax credit eligibility for renewable generation sources went into effect in January 2023 (Pisano 2022) and represent significant changes for hydropower eligibility compared to the limited credits hydropower received previously. With passage of the IRA, PTC rates are the same across generation types, and an energy storage ITC was created that supports new development and capacity additions of PSH and other energy storage facilities. However, guidance on the impact from the tax credit changes from the IRA and the specific qualification of various hydropower project types and sizes would facilitate a shared understanding of the benefits of new legislation and improve existing public documentation and guidance that is now outdated. This clarification could also encourage increased interest from tax equity investors and provide a forum for further engagement on additional incentives or solutions required to create a tax equity market for hydropower. Furthermore, increased outreach to industry to highlight these changes could be beneficial.
- **Domestic content requirements:** The IRA includes a bonus credit of 10% for PTCs or 10% for ITCs for projects that use 100% domestic content (American-made products) (Pisano 2022). At the time of interviews, stakeholders noted that they require greater clarity for how the federal government will treat hydropower subcomponents (across all project types), as they are not easy to access domestically. Developers recommended including a distinction that the subcomponents that are difficult to source domestically could be sourced internationally, as long as the remaining parts are sourced domestically.[51] As of the time of this writing, the IRS proposed domestic content rules for comment on May 12, 2023, which includes that a component is considered a U.S. component "if it is manufactured or produced in the United States, regardless of the origin of its subcomponents (IRS 2023)." The language in the proposed rule would help promote greater use of this bonus credit and improve the cost competitiveness of hydropower as compared to other renewable energy sources.
- **Proposed FDIC NPR on risk-weighted assets:** The Federal Reserve, Office of the Comptroller of the Currency, and FDIC issued an NPR on the finalization of Basel III rules on July 27, 2023 (ACORE 2023). The NPR, which is open for comment until November 30, 2023, relates to the treatment of risk-weighted assets held by banks active in the renewable energy tax equity market and has the potential to negatively impact banks' ability to finance tax equity deals. An interviewed commercial bank emphasized the importance of DOE and other government agencies understanding the implication that the change could make to the renewable energy tax equity market. The NPR proposes increasing the risk-weighted asset requirement by fourfold for equity exposures

[51] At the time of this writing, IRS has released proposed domestic content.

that investors do not publicly trade, which makes up the majority of the renewable energy tax equity market (FDIC 2023). Stakeholders recommended that DOE work together with the FDIC and other government agencies to consider changes to the proposed NPR during the open comment period, given its potential impact for all renewable energy projects in the tax equity markets.

6.2.7 Increase Awareness of New Opportunities in Hydropower and PSH

During interviews, the broader investment community, including banks, VC and PE firms, tax equity investors, and some utilities, had limited engagement with medium-sized hydropower. In addition to the focus areas identified above, the hydropower industry will also need to increase the level of engagement with the investment community in later stages of development where institutional investors and banks can support infrastructure investments for construction. To the extent possible, DOE should consider mechanisms to promote that engagement as well as support messaging around the opportunities available in new medium-sized hydropower and PSH technologies. As a trusted communicator, DOE can help to change the narrative away from the conventional perception of hydropower. Part of this work may include expanding the types of engaged stakeholders.

7 Conclusion

Medium-sized hydropower and PSH present an opportunity to generate clean power and provide additional long-duration storage for the United States, offering services that are complementary to the growth of wind and solar.[52] In this report, we looked at the hydropower investment landscape along with ways that DOE and other government agencies might help promote growth.

Hydropower developers face challenges attracting debt and equity financing due to long development timelines, the ability to identify adequate compensation opportunities, and cost competition with other renewables. While there are signs of new market activity,[53] many developers today are forced to self-fund projects to get over the early-stage development hurdles. The development risks identified in this work can be summarized into six main areas:

- **Long project development timelines:** Protracted federal, state, and local regulation processes create challenges for project developers and investors alike that add significantly to a project's financial uncertainty.
- **Lack of access to early-stage funding:** Early-stage project risks and long lead times to operational cash flows discourage investors from project involvement until permitting and licensing processes are either well underway or complete.
- **Challenges in securing early-stage PPAs:** For reasons similar to those described in the previous bullet point, offtakers are hesitant to sign PPAs until a project is close to going on-line.
- **Market compensation uncertainties and lack of market parity:** Grid compensation for services such as capacity or ancillary services vary by market and price levels are volatile, reducing revenue certainty. Complicating the situation is that state RPSs often treat hydropower and PSH differently[54] from other renewable resources, requiring them to depend more on market compensation than other renewables.
- **High up-front development costs:** Hydropower development requires significant up-front funding, and it can be years before revenue is realized. Together with market uncertainty, this can discourage investors who are seeking favorable near-term return on investment.
- **Limited industry awareness:** Lack of investor awareness about hydropower's potential role in complementing high amounts of variable renewable energy restricts hydropower's market growth. Hydropower is one of the few forms of renewable energy that is also a good source a firm capacity, a service that is helpful in cost-effectively integrating VRE onto the grid.

In closing, stakeholders who participated in this work suggested that DOE and other federal agencies have a significant role to play in incentivizing the market for hydropower and PSH

[52] For example, hydropower is an excellent source of capacity, a grid service necessary for grid reliability and helpful in the cost-effective integration of variable renewable energy technologies such as wind and solar.
[53] Notably, PE and VC funds are active investors in new hydropower technologies, some IPPs are acquiring facilities, and utilities are both acquiring and investing in infrastructure.
[54] RPSs have specific eligibility requirements that prevent some medium-sized plants from qualifying, restricting their participation in the renewable energy certificate markets.

going forward. As a next step, it is recommended that DOE investigate seven key areas to spur market growth:

- Provide financing, bridge funding, and other forms of support for early-stage hydropower development.
- Perform research on how market parity may be achieved with other types of renewables for both hydropower and PSH.
- Support the development of updated and improved market models and valuation methodologies.
- Create more awareness around federal permitting and licensing processes, and how these processes can be demystified.
- Continue to support research on reducing deployment time and costs.
- Conduct outreach with developers and other industry stakeholders prior to the implementation of new legislation and regulations to help reduce unintended consequences.
- Increase awareness of new opportunities in hydropower.

While no single stakeholder holds the key to unlocking investment in hydropower and PSH, DOE can have an important role in reducing the risks and costs in these areas, which should help accelerate future investment, enabling further VRE integration.

Glossary

Term	Definition
Acquisition	Transactions in which a company or organization transfers the ownership of an asset (or portfolio of assets) to a purchasing company or organization.
Ancillary Services	Capacity and energy services (e.g., non-spinning operating reserve, frequency support, voltage support) provided by power plants that are able to respond on short notice, such as hydropower plants, and are used to ensure stable electricity delivery and optimized grid reliability. Also called grid services.
Bankability	The ability of a project to interest investors to provide investment into a project, usually signifying that the project's economics provide positive returns and that risks are minimal (and/or are commensurate with the investor's risk appetite).
Black Start	Allows operations to be restored after a systemwide power outage. Almost all generators require some input to begin operation. Black-start resources are usually energy storage resources or generators that are equipped with a diesel generator to provide input power upon starting the generator.
Bond	A fixed-income financial instrument that represents a loan (debt) made effectively by a group of investors, typically at a fixed interest rate.
Capacity Addition	This category includes additions of new turbine generator units to existing hydropower projects, as well as upgrades to existing turbine-generator units, which result in an increase in unit nameplate capacity.
Capacity Market	A market that aids resource adequacy efforts and reliability requirements. The capacity market is a mechanism intended to ensure an adequate amount of generation will be on the grid to meet demand in years to come. ISO/RTOs create price signals that are a function of capacity relative to peak demand.
Community Choice Aggregatory (CCA)	Programs that permit local governments to procure power on behalf of their residents, businesses, and municipal accounts from an alternative supplier, often a way to incorporate more renewable energy. CCAs can still receive transmission and distribution service from their existing utility provider.
Conduit	Hydropower project where hydropower generation capability is added to an existing conduit ("any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar man-made water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption and not primarily for the generation of electricity" 18 CFR 4.30). Includes run-of-river hydropower.

Term	Definition
Debt	A loan provided by one or more party (the lender) to another party (the debtor), in which the loan must be repaid under specified conditions, including a defined loan tenor and interest rate. Infrastructure projects often rely on debt financing to allow for cheaper financing (and lower cost of capital) for project development.
Decommission	Complex regulatory and engineering process to remove a dam from service to reestablish natural flows.
Developer	Private companies and utilities who lead planning and construction of hydropower or PSH projects.
Exemption	A simplified process with FERC for small hydropower projects up to 10 MW that will be built at an existing dam or with other low-impact features.
Frequency Regulation	A common ancillary service offered in every ISO/RTO by which regulation service pays producers to balance small fluctuations between supply and demand in real time.
Guarantee (Loan Guarantee)	An agreement (or guarantee) that a third party will assume responsibility for and repay outstanding debt if the debtor defaults on its debt obligations to a lender.
Hybrid-Plant Configuration	Plants where two or more generators of different technologies, or a generator and a storage device, are paired at a single interconnection point.
Independent Power Producer	A private entity, rather than public utility, which owns electricity generating assets and sells power to users, utilities, or other corporate offtakers.
Independent System Operator	Organization that coordinates, controls, and monitors operation of the electrical power system within a specified geographic region.
Levelized Cost of Energy (LCOE)	The measure of lifetime project costs divided by lifetime energy production, resulting in the total present value cost of operating a power plant. LCOE characterizes the average price in \$/kWh or \$/MWh.
License	FERC-issued approval to construct, operate, and maintain nonfederal hydropower projects.
Medium-Sized Hydropower	As defined in this report, hydropower facilities with a generation capacity of 5 to 30 MW.
Net Metering	System which allows for residential and commercial customers who generate their own electricity to sell any excess electricity back to the grid.
New Stream-Reach Development	Hydropower project where hydropower generation capability is added to previously undeveloped sites and waterways.

Term	Definition
Offtaker	The purchaser of power from an electricity generator, which are primarily either utilities or corporations.
Pipeline	Projects that are in some stage of the planning process but are not yet in operation.
Plant Expansion	Addition of new turbine-generator units (in existing or new powerhouse) at existing hydropower project.
Plant Refurbishment	Projects that involve modifications in turbine-generator units or other elements of a hydropower plant to extend the life of the facility and improve its performance but do not result in increased generating capacity or increased energy output.
Preliminary Permit	FERC gives authorization for a permittee to file a license application while it gathers data and studies the feasibility of developing a proposed project at a particular site.
Pumped Storage Hydropower	A type of hydroelectric energy storage that utilizes two water reservoirs at different elevations that can generate power as water moves down from one to the other (discharge), passing through a turbine. A closed-loop plant consists of two reservoirs that are not connected to naturally flowing sources of water. An open-loop plant consists of two reservoirs that are continuously connected to naturally flowing sources of water.
Non-Powered Dam	Hydropower project where hydropower generation capability is added to an existing dam that is used solely for other purposes (e.g., flood control, navigation).
Rate Base	The value of net assets on which a rate of return is allowable.
Relicense	FERC-issued approval to construct, operate, and maintain nonfederal hydropower projects at a site which is already used for hydropower and has a license which is set to expire soon.
Renewable Energy Certificate (REC)	A market mechanism that assigns one certificate to each megawatt-hour of generation sent to the grid. Many regulators mandate that a percentage of energy produced by utilities come from renewable resources. RECs allow regulators to track who owns the rights to renewable energy that has been generated

Note: Some of the definitions included above come from the authors' industry experience or are copied verbatim from the U.S. Hydropower Market Report (Uría-Martínez and Johnson 2023), the Water Power Technologies Office Multi-Year Program Plan (DOE 2022), or the Water Power Technologies Office Glossary of Hydropower Terms (https://www.energy.gov/eere/water/glossary-hydropower-terms).

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Appendix A. Recent Medium-Sized Hydropower and Pumped Storage Hydropower Transactions (2013–2023)

The authors analyzed transaction data from the ORNL HydroSource database, Infralogic, S&P Capital IQ, FERC, and industry websites. The transaction data provides an illustrative view of recent investments to understand industry trends, which is based upon publicly available information. The tables below summarize recent medium-sized hydropower and PSH transactions (2013–2023) carried out by private project developers and IPPs, PE and VC funds, and utilities.

Table A-1. Recent Transactions (2013–2023) by IPPs and Private Project Developers in Medium-Sized Hydropower and PSH[55]

IPP/Developer	Portfolio and Recent Transactions/Projects	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Atlantic Power Co Owns two hydropower facilities with 65 MW total capacity in British Columbia	Acquired remaining 50% stake in Koma Kulshan Hydroelectric Facility (Power World Analysis 2018)	Acquisition	2018	Purchased from Covanta	$13.2	13.3 MW / Yes
Eagle Creek Renewable Energy Owns/operates 85 hydropower facilities with 691 MW total capacity (Eagle Creek Renewable Energy 2023a)	Acquired 10 hydropower facilities with 12 MW capacity in three different transactions (Sulehri 2016)	Acquisition	2016	Acquired Epico USA Inc.; purchased facilities from private investors	Undisclosed	12 MW / Yes
	Acquired Koma Kulshan 13 MW project for $24 million in 2022 (S&P Capital IQ 2022)	Acquisition	2022	Purchased from Atlantic Power Co.	$24	13.3 MW / Yes
	Commissioned two new power houses on USACE dams at Ball Mountain and Townshend Dams on West River of total 3.1 MW capacity (Eagle Creek Renewable Energy 2023b)	Infrastructure Investment (NPD)	2016	Partnership with USACE	Undisclosed	3.1 MW / No

[55] This table demonstrates trends in recent investment and may not be inclusive of all transactions.

IPP/Developer	Portfolio and Recent Transactions/Projects	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
	Purchased Reusens facility and rehabilitated four of its five generation units (Eagle Creek Renewable Energy 2023c)	Acquisition	2017	Purchased from AEP	Undisclosed	10 MW / Yes
Enduring Hydro Established to develop new hydroelectric facilities	Acquisition of Mahoning Creek Hydroelectric Dam from Advanced Hydro Solutions in 2012	Acquisition	2012	Purchased from Advanced Hydro Solutions	$16	6 MW / Yes
FirstLight Power Own/operate 20+ hydropower facilities across the U.S. and Canada (FirstLight 2023)	Acquired 13.6 MW Allegheny 8 project and 17.9 MW Allegheny 9 project from H2O Power in 2022 (Business Wire 2022)	Acquisition	2022	Purchased from H2O Power	Undisclosed	31.5 MW / Yes
	Integrated with H2O Power in 2023 to hold majority stake in eight hydroelectric facilities across Ontario (FirstLight 2023)	Acquisition	2023	Integrated with H2O Power	Undisclosed	150 MW / Yes (7 of 8 facilities are medium-sized)
HSE Hydro NH AC Subsidiary of PE firm Hull Street Energy LLC	Acquisition of Eversource 68 MW Portfolio	Acquisition	2018	Purchased from Eversource Energy	$83	68 MW / Yes (for individual facilities)
HydroLand Owns at least 15 U.S. hydroelectric facilities (Hydroland 2021; Hydro Review 2021b)	Acquired 13 run-of-river hydropower facilities in 2021 with combined generation capacity of 25 MW from Enel Green Power (Hydroland 2021)	Acquisition	2021	Purchased from Enel Green Power; GLC Advisors & Co. (Financial Advisor)	Undisclosed	25 MW / Yes

IPP/Developer	Portfolio and Recent Transactions/Projects	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Innergex Renewable Energy Inc Own/operate 40 hydropower facilities, with a total capacity of 919 MW (Innergex 2023)	Acquired 12 MW Curtis Mills and 48 MW Palmer Falls facilities from Atlantic Power Company in 2021 (Innergex Renewable Energy 2021)	Acquisition	2021	Purchased from Atlantic Power Co.; HQI U.S. Holding LLC (Co-Lead)	$310	60 MW / Yes
Kern & Tule Hydro LLC California-based hydropower LLC	Acquired 11.5 MW Kern facility and 6.4 MW Tule Hydropower Plant, both in California, from PG&E in 2020 (KGET 2020)	Acquisition	2020	Purchased from PG&E	Undisclosed	17.9 MW / Yes
LS Power Owns/operates more than 13,000 MW renewable energy generation (LS Power 2023)	Acquired portfolio of 42 hydropower projects in 2022 from Hull Street Energy, totaling 334 MW (Hydro Review, 2022)	Acquisition	2022	Purchased from Hull Street Energy; BMO Capital Markets Corp. and Scotiabank (Financial Advisors)	$390	334 MW/ Yes (on average)
	Acquired portfolio of 11 hydroelectric power stations from FirstEnergy Corp (FirstEnergy 2014).	Acquisition	2014	Purchased from First Energy	$395	527 MW / Yes (2 of 11 facilities are medium-sized)
Northbrook Energy Has owned/managed 26 hydropower facilities over past 30	Acquired 18.75 MW Duke Energy Western Carolinas Hydropower Portfolio in 2018 (Duke Energy 2018)	Acquisition	2019	Purchased from Duke Energy; New Energy Capital Partners (Other Investor)	$4.75	18.75 MW / Yes

IPP/Developer	Portfolio and Recent Transactions/Projects	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
years (Northbrook Energy 2023)	Acquired 10.5 MW Pinnacles Hydropower Plant in 2021 for $8.2 million from the City of Danville (Danville, Virginia 2022)	Acquisition	2021	Purchased from City of Danville	$8.2	10.5 MW / Yes
rPlus Energies Own/operate more than 40 projects with 14+ GW of renewable energy capacity (rPlus Energies 2023)	Created rPlus Hydro in 2019 in partnership with Gridflex Energy, which has 12 projects with combined capacity 9,000+ MW (rPlus Hydro 2023)	Corporate Investment	2019	N/A	Undisclosed (rPlus Hydro 2023)	N/A

Table A-2. Recent Transactions (2013–2023) by PE and VC Funds in Medium-Sized Hydropower and PSH[56]

PE/VC Investor	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
ArcLight Capital Partners Middle-market, value-added infrastructure firm founded in 2001	Acquired Great River Hydroelectric Facilities (13 generating stations, three storage reservoirs) from TC Energy	Acquisition	2017	Purchased from TC Energy, with support from ArcLight Energy Partners Fund VI	$1,065	584 MW / Yes (some of the generating stations)
Axium Infrastructure Independent portfolio management firm created in 2009	Acquisition of Upper Peninsula Power Company, which has seven hydropower facilities (Axium 2021)	Acquisition	2021	Purchased from Basalt Infrastructure Partners	Undisclosed	80 MW / Yes (individual hydropower facilities)
Breakthrough Energy Ventures (BEV) Investment firm seeking to launch companies that will eliminate GHG emissions, founded by Bill Gates in 2015	Led $20 million Series B funding round in Natel Energy (2021) (Natel Energy 2021)	Corporate Investment	2020	Investors include: Schneider Electric Ventures (2020); Breakthrough Ventures (2020); Breakthrough Energy Ventures (Lead) (2021), and Chevron Tech-nology Ventures (2021), Japan Energy Fund (2023)	$11 (Inter-national Water Power and Dam Construction 2020)	N/A
Brookfield Infrastructure Partners (BIP) One of the largest owners and operators of global infrastructure networks, founded in 2008 as an affiliate of Brookfield Asset Management (Brookfield Infrastructure Partners 2023)	Malacha Hydroelectric Facility Acquisition (50% stake) (Brookfield Asset Management 2014)	Acquisition	2013	Purchased remaining 50% from Malacha Hydro Limited Partnership	Undisclosed	30 MW / Yes

[56] This table demonstrates trends in recent investment and may not be inclusive of all transactions.

PE/VC Investor	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
CAI[57] Infrastructure investment firm focused on low-carbon assets that raised over $1 billion in 2022	Financed Rye Development's pipeline of 22 FERC-licensed NPD projects with total capacity of 246 MW in 2021 (State of CT 2021)	Corporate Investment	2020	Developed by Rye Development in partnership with USACE	$125 (State of CT 2021)	N/A
FullCycle Climate Partners Invests in growth stage climate technology companies	Invested in InPipe Energy (FullCycle 2021)	Corporate Investment	2021	Investment in InPipe Energy	Undisclosed	N/A
Greenbacker Capital Management (GCM) Independent power producer and investment manager focused on green energy (Greenbacker Capital 2023)	Invested in Clear Energy Hydro, developer that acquires and modernizes existing small hydropower facilities (2021) (Greenbacker Capital 2021)	Corporate Investment	2021	Investment in Clear Energy Hydro	Undisclosed (Greenbacker Capital 2021)	N/A
	Invested in Dichotomy Power, a hydropower developer and owner/operator (2020) (Hydro Review 2020b)	Corporate Investment	2020	Investment in Dichotomy Power	Undisclosed (Hydro Review 2020b)	N/A

[57] Notably, Connecticut Retirement Plans and Trust Funds, a pension fund and institutional investor, invested $125 million in 2022 in CAI (Kozlowski 2022).

PE/VC Investor	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Hull Street Energy Leading energy-focused PE firm with controlling equity investments in nine middle-market energy companies (Hull Street 2023)	Acquired 31 hydroelectric facilities with 255 MW of capacity from EGPNA REP in 2020 (Hull Street Energy 2020)	Acquisition	2020	Purchased from EGPNA REP (joint venture between Enel Green Power North America and GE Energy Financial Services)	$130	255 MW / Yes (some individual facilities in medium-sized range)
	Made a controlling equity investment in Serium Energy Storage, LLC (Serium 2023)	Corporate Investment	2020	Additional investment from Albany Engineering	Undisclosed	N/A / No
I Squared Capital PE firm focused on global infrastructure investments founded in 2012	Acquired Enduring Hydro and formed Cube Hydro Partners	Corporate Investment	2014	Acquired Enduring Hydro	$140 (Stutts 2015)	N/A
	Acquired York Haven Hydropower Plant under Cube Hydro, portfolio company of I Squared (Hopson 2015)	Acquisition	2015	Purchased from York Haven Power Co.	Undisclosed	20 MW / Yes
	Acquired Atlantic Power Co.	Acquisition	2021	Acquired Atlantic Power Co.	Undisclosed	N/A
Industrial Alliance Insurance and Financial Services One of Canada's largest insurance and wealth management groups.	Provided non-recourse debt for Dorena Lake and Clark Canyon run-of-river Hydroelectric Retrofit projects (PowerInfo 2019)	Infrastructure Investment (NPD)	2016	Additional debt provided by Aquila Infrastructure Management; project developed by Riverbank Power Corp	$38	12.2 MW / Yes
Lorem Partners Small investment firm with four company investments	Founding shareholders and directors of Gravity Renewables, Inc. (Hydro Review 2013)	Corporate Investment	2013	Additional investment from Canoe Financial and Energy Development Group	$3	28 MW (at time of investment) / Yes

PE/VC Investor	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Oval Park Capital (OPC) Investment firm focused on large global industries, founded in 2018 (Oval Park 2023)	Lead investor in $18.4 million Series A funding round for Emrgy, a turbine equipment manufacturer and developer (2023) (International Water Power and Dam Construction 2023)	Corporate Investment	2022	Other Investors: Qatalyst Ventures (2022), the Conduit Connect (2022), the Jump Fund (2022), Village Capital (2022); Oval Park Capital (Lead), Fifth Wall (2023), Blitzscaling Ventures (2023), Overlay Capital (2023), and Veriten (2023)	$18 (International Water Power 2023)	N/A
Vantage Infrastructure Independent infrastructure specialist manager providing equity and debt	Provided debt to refurbish Hull Street New England Portfolio	Infrastructure Investment (Refurbishment)	2020	Debt provided to Hull Street Energy	$66	87 MW / Yes (some individual facilities)

Table A-3. Recent Transactions by Utilities in Medium-Sized Hydropower and PSH[58]

Utility	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Alaska Power & Telephone (AP&T) Own/operate seven hydropower facilities with 15 MW total capacity (Hydro Review 2020a)	Commissioned 5 MW Hiilangaay Hydro Project in Prince of Wales Island, Alaska, in 2020 (Thayer 2023)	Infrastructure Investment (NPD)	2016	Haida Energy co-owns plant, $4M grants and loans from Alaska Energy Authority	$31.3	5 MW / Yes
City of St Cloud, Minnesota Own/operate 8.9 MW St. Cloud Hydropower Dam, largest city-owned dam in Minnesota (City of St. Cloud, Minnesota 2023)	City of St. Cloud issued taxable hydroelectric revenue bonds in 2016 to finance various improvements to the St. Cloud Hydropower Dam (EMMA 2023)	Infrastructure Investment (Refurbishment)	2016	N/A	$3.13	8.86 MW / Yes
Duke Energy Corporation Began operations exclusively as a hydropower company and now has a diverse portfolio of renewables	Completed Great Falls hydro enhancement project to make recreational and environmental enhancements required for relicensing (Ingram 2023a)	Infrastructure Investment (Refurbishment)	2023	N/A	Undisclosed	24 MW / Yes

[58] This table demonstrates trends in recent investment and may not be inclusive of all transactions.

Utility	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
East Texas Electric Cooperative (ETEC) Owns/operates three hydropower facilities	Commissioned 24 MW R.C. Thomas Hydropower Project in 2021, financed using Clean Renewable Energy Bonds and $73 million loan from USDA Rural Utilities Service (Chase-Israel 2022)	Infrastructure Investment (NPD)	2015	Loan provided by USDA	$158	24 MW / Yes
Grand Valley Water Users Association Private nonprofit local water association with partnership in one hydroelectric power plant	Self-invest in Vinelands Power Plant (Webb 2021)	Infrastructure Investment (Capacity Addition)	2020	Co-developed and invested by Orchard Mesa Irrigation District	$10	4.9 MW / Yes
Hydro-Quebec Canadian public utility Crown corporation managing electricity in Quebec	Acquired Great River Hydroelectric Facilities (13 generating stations, three storage reservoirs) from ArcLight Energy Partners Fund VI and ArcLight Capital Partners	Acquisition	2023	Purchased from ArcLight Energy Partners Fund VI and ArcLight Capital Partners	$2,250	589 MW / Yes (some of the generating stations)
Ontario Power Generation Canadian public utility Crown corporation responsible for about half of Ontario's electricity generation	Acquired Cube Hydro from I Squared Capital (Falconer 2019)	Acquisition	2019	Purchased from I Squared Capital	$1,123	385 MW / Yes (some assets under Cube Hydro)

Utility	Portfolio and Recent Investments/Transactions	Transaction Type	Year	Other Parties	Investment Amount ($ million)	Portfolio or Facility MW / Qualifies as Medium-Sized?
Sacramento Municipal Utility District Electric utility in California with 11 reservoirs and nine powerhouses that meet 20% of customer demand	Acquired Chili Bar Hydroelectric Project from PG&E in 2019 (News Release 2021)	Acquisition	2019	Purchased from PG&E	$10.4	7 MW / Yes
Snohomish County Public Utility District (PUD) No. 1 Owns/operates five hydropower projects with total capacity of 70.9 MW (Snohomish 2023)	Raised $52 million in tax-exempt bonds to finance construction of two 6 MW hydropower projects (Calligan Creek and Hancock Creek) which were completed in 2018 (Catchpole 2015)	Infrastructure Investment (NPD)	2015	Undisclosed	$52 ($24 for Calligan, $28 for Hancock)	12 MW (6 MW, 6 MW) / Yes
Xcel Energy Own/operate 26 hydropower facilities with combined capacity of more than 370 MW (Xcel Energy 2023)	Began 7.2 MW spillway modernization project in 2022 for Cedar Falls hydropower facility (Xcel Energy 2022)	Infrastructure Investment (Refurbishment)	2022	N/A	$50	7.2 MW / Yes

Appendix B. Federal Hydropower Incentive Programs

Table B-1 highlights primary examples of federal hydropower incentive programs.

Table B-1. Federal Hydropower Incentive Programs

Program	Funding/ Financing Type	Appropriated Amount[59]	Description[60]
Internal Revenue Service (IRS) Production Tax Credit (PTC)	Tax Credit	N/A	Federal PTC most often used for wind projects with awards of $5.50/MWh to $33.00/MWh of electricity produced, applicable to capacity upgrades at existing hydropower facilities, retrofits of NPDs with hydropower generation, new marine energy projects, and pressurized conduits (WPTO 2023a). Credit rate depends on project size, compliance with wage and apprenticeship requirements, and qualification for the energy community bonus and/or domestic content bonus. The PTC is typically applicable for the initial 10 years of operation. PTC is scheduled to sunset in 2024, at which point it will be replaced by the Technology-Neutral Clean Energy Generation Tax Credit from 2025 to 2032. The IRA updated the existing policy of half-credit for waterpower projects, so all projects placed in service after December 31, 2022, will receive the full credit, equivalent to that of wind projects (Pisano 2022). Projects eligible for the PTC may elect instead to claim the ITC, detailed below.
IRS Investment Tax Credit (ITC)	Tax Credit	N/A	Federal ITC for energy property, most often used for solar projects, which offers a 6% to 50% tax credit for the cost of building renewable energy systems, including PSH, or for qualified facilities under the PTC (see above) in lieu of PTC credits (WPTO 2023a). Credit rate depends on project size, compliance with wage and apprenticeship requirements, and qualification for the energy community bonus and/or domestic content bonus. ITC is scheduled to sunset in 2024, at which point it will be replaced by the Technology-Neutral Clean Energy Generation Tax Credit from 2025 to 2032 (Pisano 2022). Prior to the IRA changes going into effect in December 2022, energy storage systems were not eligible for ITC.
IRS Technology-Neutral Clean Energy Generation Tax Credit	Tax Credit	N/A	Federal investment tax credit set to replace the PTC and ITC starting in 2025 and lasting until 2032. To qualify, projects must be used for the generation of electricity, be placed in service after December 2024, and have a zero or negative greenhouse gas emissions rate. Qualifying projects may elect to receive either a PTC or an ITC. The credit will begin a 3-year phase out if U.S. carbon emissions from the electricity sector are reduced by 75% compared to 2022 levels before 2032 (Pisano 2022).

[59] Appropriated Amount: Represents the funding allocated for the respective incentive programs to support hydropower projects.
[60] "Description" column provides details on source of funding. For initiatives with a long tenure, this number does not describe the total allocations across the lifetime of the initiative.

Program	Funding/ Financing Type	Appropriated Amount[59]	Description[60]
USACE CWIFP (USACE 2023b)	Debt	$7.5 billion (lending capacity)	USACE's new federal loan program, which has received $81 million for credit subsidy and an additional $22.6 million for program administration; finances projects that maintain, upgrade, and repair dam infrastructure across the United States, limited to nonfederal dams. CWIFP will provide long-term, low-cost loans "for up to 49% of project costs, or up to 80% of project costs for projects that serve economically disadvantaged communities" (Ingram 2023b). Projects must have eligible costs in excess of $20 million to qualify. The program has $7.5 billion in lending capacity.
DOE LPO EIR Loan	Debt	$5 billion, to support loan guarantees up to $250 Billion	Established under the IRA and administered by the LPO, the EIR Program provides direct loans and partial guarantees to bolster energy infrastructure reinvestment across the United States, including in designated DOE energy communities, as an addition to DOE LPO's Title 17 Clean Energy Financing Program (LPO 2023a). The IRA appropriates $5 billion through September 2026 to support loan guarantees up to $250 billion for projects that retool, repower, repurpose, or replace inactive energy infrastructure (LPO 2022). It also finances initiatives that help existing energy facilities mitigate, reduce, capture, or utilize air pollutants or greenhouse gas emissions. Title 17 loans commonly cover 40%–60% of project costs.
DOE Hydroelectric Production Incentives (EPAct Section 242)	Incentive Payment	$125 million	Provides $125 million via the IIJA for hydropower facilities, with particular emphasis on facilities in communities with inadequate electricity provision. Provides payments for electricity generated and sold from new or expanded hydroelectric facilities, specifically for NPDs, conduits, and capacity additions (GDO 2023c).
DOE Hydroelectric Efficiency Improvement Incentives (EPAct Section 243)	Incentive Payment	$75 million	Provides $75 million via the IIJA for existing hydropower and pumped storage facilities to make capital improvements to improve efficiency by at least 3% (GDO 2023d).
DOE Maintaining and Enhancing Hydroelectricity Incentives (EPAct Section 247)	Incentive Payment	$554 million	Provides $554 million specifically for capital improvements on existing hydropower projects that impact grid resiliency, dam safety, and environmental improvements (DOE GDO 2023b).
DOE OCED Long-Duration Energy Storage Demonstrations (BIL Section 41001)	Grant	$505 million	Provides $505 million to technology developers, industry, state and local governments, Tribal organizations, and others to carry out demonstration projects which will help innovative long duration energy storage technologies become commercially viable. These demonstrations can contribute to supplying energy at peak periods of demand and providing ancillary services for grid stability (OCED 2023c).

Program	Funding/ Financing Type	Appropriated Amount[59]	Description[60]
DOE GDO Grid Innovation Program (BIL Section 40103(b))	Grant	$5 billion	Provides $5 billion in grant funding to governmental entities to collaborate with owners and operators to demonstrate new and innovative approaches to enhancing regional grid resilience. Advanced distribution grid assets and functionality, including storage, qualify for the grants (DOE Clean Energy Infrastructure 2023).
DOE OCED Energy Improvements in Rural or Remote Areas (ERA) program (BIL Section 40103 (c))	Grant	$1 billion	Aims to advance energy improvements and promote sustainable energy solutions in communities across the country with 10,000 or fewer people. Provides grants and technical assistance to advance clean energy demonstrations and energy solutions that are replicable and scalable. The program will provide $200 million annually for FY22 to FY26. The program can be used to improve the overall cost-effectiveness of energy generation, transmission, or distribution systems (OCED 2023b).
DOE OCED Clean Energy Demonstration Program on Current and Former Mine Land (BIL Section 40342)	Grant	$500 million	Authorized by the Bureau of Land Management and carried out by DOE, provides financial investment and technical assistance to advance deployment of clean energy projects on current and former mine land. The program received $500 million from the BIL and will support projects by providing up to 50% of the cost (in the range of $10 million–$150 million) for a 5-year period from FY22 to FY26. Funding will go toward demonstration projects that are commercially viable, including energy storage projects like PSH (OCED 2023a).
USDA Powering Affordable Clean Energy (PACE) program (IRA Section 22001)	Debt, Grant	$1 billion	As part of the IRA, USDA Rural Development's Rural Utilities Service (RUS) will forgive up to 60% of loans for utility-scale clean energy projects. Hydropower and PSH projects which serve a population that is at least half rural (communities with populations of 20,000 or fewer qualify). Projects must have bankable PPAs or financial guarantees to qualify. Loans range from $1 million to $100 million, with a total of $1 billion in authorized funding (USDA Rural Development 2023b).
USDA Empowering Rural America (New ERA) program (IRA Section 22004)	Debt, Grant	$9.7 billion	USDA provides rural electric cooperatives with loans, grants, and loan refinancing to support energy efficiency improvements, deploy zero-emission systems, or purchase renewable energy. To qualify, the cooperative's service territory must be at least 50% rural and prioritizes technologies that have the greatest capacity to reduce greenhouse gas emissions. Grants can equal no more than 25% of the project cost (USDA Rural Development 2023a).

Program	Funding/ Financing Type	Appropriated Amount[59]	Description[60]
USDA Rural Energy for America Program (REAP) (IRA Section 22002)	Grant, Guarantee	$1 billion	USDA provides loan guarantees and grants to agricultural producers and small businesses aiming to deploy renewable energy systems or make energy efficiency improvements. Eligible projects include medium-sized hydropower in rural areas with populations of 50,000 residents or fewer. Loan guarantees can be provided on loans up to 75% of eligible project costs, and grants can cover up to 50% of eligible project costs in the range of $1,500 to $1 million. The program has $1 billion in IRA funds available from March 2023 through September 2024 (USDA Rural Development 2023c).